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Municipal Waste Combustion: Background Information for Materials Separation

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Several issues related to materials separation from municipal solid waste (MSW) are discussed. Current nationwide rates of materials separation and recycling, as well as the methodology for determining municipal solid waste separation rates, are presented. Case studies of four community curbside separation programs include performance data and program costs. Two centralized materials separation facilities which separate materials from unsorted MSW are described with respect to the separation mechanisms employed, performance, and available cost data.

Available data on the impacts of materials separation on municipal waste combustor (MWC) air emissions, combustor operation, and MWC ash are presented. The potential occupational risks of the handpicking process used to separate materials from MSW at some centralized separation facilities are discussed. The use of mercury in household batteries, and current information on community battery separation and collection programs and recycling efforts, are also discussed.

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1.0 INTRODUCTION

New source performance standards (NSPS) for new municipal waste combustors (MWC's) and emission guidelines for existing MWC's were proposed on December 20, 1989, under Section 111 of the Clean Air Act (CAA) (FR 54 52251 and 52209, respectively). The proposed standards and guidelines contain provisions for controlling MWC air emissions by requiring three control elements: (1) front-end materials separation, (2) good combustion practices (GCP), and (3) add-on air pollution control devices (APCD's). The proposed regulations for materials separation require that 25 percent of the weight of municipal solid waste (MSW) be separated for recovery and not combusted. The proposed 25 percent separation is determined on a yearly average basis. The proposed regulations for materials separation also contain a requirement that a lead-acid vehicle battery separation program be implemented for all MWC's.

In developing the proposed regulations for MWC's, the Agency identified several issues related to materials separation which required further study. The purpose of this report is to provide further technical information on these issues.

Chapter 2.0 of this report discusses current nationwide levels of materials separation. Chapter 3.0 presents case studies of four existing curbside community materials separation programs. These case studies provide materials separation program performance data as well as program costs. Chapter 4.0 describes case studies of two centralized materials separation facilities which separate materials from unsorted MSW. These case studies give descriptions of the separation mechanisms employed at the two facilities. Performance data and costs are also provided where available.

Chapter 5.0 discusses available data on the impacts of materials separation on MWC air emissions, combustor operation, and MWC ash.

Chapter 6.0 discusses the potential occupational risks of the handpicking process used to separate materials from MSW at some centralized separation facilities. Finally, Chapter 7.0 discusses the use of mercury in household batteries and provides current information on community household battery collection programs and household battery recycling efforts. Additionally, Appendix A describes materials separation documentation and reporting procedures and provides sample reporting forms that could be used to track amounts of materials separated.

2.0 CURRENT RATES OF MATERIALS SEPARATION AND RECYCLING

This section presents information on current rates of materials separation and recycling in the United States. Many States and communities have been implementing materials separation programs in recent years, and the amount of materials separation taking place in the United States is increasing. In most areas, some degree of MSW materials separation occurs in the public and private sectors regardless of whether there is a Federal, State, or local recycling program. For instance, aluminum cans are often separated in the public and private sectors, most supermarkets separate and bail waste cardboard for shipment to a paper broker or paper mill, and, in most medium or large communities, there are scrap metal dealers who buy materials such as scrap steel or scrap copper from both public and private sectors. Section 2.1 discusses methods for determining MSW separation rates, and Section 2.2 presents current estimates of materials separation as a proportion of nationwide generation of MSW.

2.1 METHODOLOGY FOR DETERMINING MUNICIPAL SOLID WASTE SEPARATION RATES

There are two methods for determining the rate of MSW separation in a particular area. The first method involves actual weight (or volume) measurements of materials separated. With this method, the weight of separated materials is compared to the weight of materials disposed of in landfills or combusted in MWC's. This ratio determines the overall percentage of materials separated. Separated materials exchanged in the private sector by businesses or nonprofit groups are usually weighed at some point since materials are usually bought and sold on a weight basis. Separated materials collected by municipal collection programs such as glass, paper, and aluminum cans are normally weighed on scales owned by the municipality, or they are weighed by the buyer when the materials are taken to market. Sometimes the weight of the materials separated is estimated based on volume. For instance, most communities estimate the weight of leaves or other yard waste collected on a truck count basis based on the average weight of a certain size truckload of that material which has been determined in previous weight measurements.

If the total weight of MSW disposed of in a landfill or an MWC and the total weight of materials separated is known, the separation rate can be determined simply by dividing the weight separated by the sum of the weight disposed and the weight separated. Most all MWC's have such scales, but many smaller landfills will not. Additionally, obtaining records of weights of all materials separated in a given service area may be difficult. For example, some supermarkets separate cardboard and ship it to a central warehouse where cardboard from other stores of the same company are stored. In such cases, the cardboard is shipped out of the service area and stored with materials from many other service areas. When these materials are taken to market, they are weighed together, but the amount of cardboard from a specific store in a given service area is not known. Similarly, materials brokers in large cities may buy and sell paper or metals from individuals or small businesses from communities in several service areas and it may be difficult to get exact weights of materials received from a given service area. Some private materials dealers often refuse to divulge information on weights of materials traded because they view the information as proprietary.

The second method for determining materials separation rate is a materials flow approach. Government or industry trade association data are used to estimate amounts of goods produced or consumed, and these data can be used on a national level to estimate the amounts of MSW generated in this area. Industry trade association data for consumption of secondary materials can be used to estimate the amounts of materials separated for recovery. On a State or local level, data from major materials brokers or manufacturers which use secondary material may be used.

The materials flow approach tends to be more accurate on a national scale. Such statistics are generally not applicable to smaller areas. Furthermore, while these types of data can be obtained for materials such as glass, plastics, and metals, no such data are available for yard waste, food waste, wood waste, or some other materials which are not traded in secondary markets. For these materials, waste generation and separation must be estimated by extrapolating from historical data on measurements of the composition and separation rates of MSW.

2.2 NATIONWIDE AVERAGE MATERIALS SEPARATION RATES

A 1988 Environmental Protection Agency (EPA) study estimated the total amount of MSW discarded in the United States and the proportion of those discards which were separated for recovery.[1] The study used a materials flow approach for estimating discards and recovery of durable goods (e.g., appliances, furniture, tires), nondurable goods (e.g., newspapers, office papers, clothing), and containers and packaging (e.g., cans, bottles, boxes, bags, wrapping). Estimates of the amounts of food waste, yard waste, and miscellaneous inorganic wastes, disposed of were made based on numerous landfill sampling surveys. No estimates were available for separation of these materials.

Table 2-1 presents the estimated quantity and percentage of individual materials discarded in the United States in 1986 and the estimated quantity and percentage of these materials which were separated for recovery.[1] As shown in the table, about 160 million tons of MSW were discarded in the United States in 1986. About 11 percent of these discards were separated for recovery while the remaining 89 percent was disposed of in landfills or MWC's.

Corrugated containers and other paperboard packaging accounted for nearly half of the MSW materials recovered in the United States in 1986 (about 5 percent of the total MSW). All paper products together, including paper packaging as well as nondurable goods such as newspapers and office papers, accounted for over 85 percent of the MSW materials separated for recovery. Glass, aluminum, and durable goods make up the majority of the remaining materials separated for recovery.

Since the majority of these data are based upon the total industrial production of goods or use of secondary materials, there is no way to determine the proportion of waste discards or materials separation attributed to the residential, institutional, or commercial sectors. For instance, trade association data may give the total tons of office paper recycled by paper industries, but there are no data for what proportion of this paper comes from schools, homes, government offices, or commercial businesses. There is also no way to differentiate the amounts separated by both community programs or private initiatives. However, it is probable

TABLE 2-1. NATIONWIDE GROSS DISCARDS AND RECOVERY OF MSW IN 1986[1]

Products	Gross Discards		Materials Recovery		
	Quantity (tons x 10^6)	Percent of Gross Discards	Quantity (tons x 10^6)	Percent Recovery for Category	Percent Recovery for Gross Discards
NONDURABLE GOODS					
Newspapers	12.6	8.0	3.8	30.2	2.4
Books and Magazines	4.8	3.0	0.4	8.3	0.3
Office Papers	6.1	3.9	1.1	18.0	0.7
Commercial Printing	3.7	2.3	0.5	13.5	0.3
Other Nonpackaging Paper	8.5	5.4	0.2	2.4	0.1
Other Miscellaneous Nondurables	5.8	3.7	0.0	0.0	0.0
TOTAL NONDURABLE GOODS	41.5	(26.3)[a]	6.0	(14.5)	(3.8)
CONTAINERS AND PACKAGING					
Glass Containers:					
Beer & Soft Drink Cans	5.5	3.5	1.1	20.0	0.7
Other Glass Containers	6.3	4.0	Neg.[b]	0.0	0.0
Subtotal - Glass	11.8	(7.5)	1.1	(9.3)	(0.7)
Steel Containers:					
Beer & Soft Drink Cans	0.1	0.1	0.0	0.0	0.0
Food Cans	1.8	1.1	0.1	5.6	>0.1
Other Steel Packaging	0.9	0.6	Neg.	0.0	0.0
Subtotal - Steel	2.8	(1.8)	0.1	(3.6)	(0.1)
Aluminum:					
Beer & Soft Drink Cans	1.3	0.8	0.6	46.2	0.4
Other Aluminum Packaging	0.4	0.3	Neg.	0.0	0.0
Subtotal - Aluminum	1.7	(1.1)	0.6	(35.3)	(0.4)
Paper and Paperboard:					
Corrugated Containers	19.4	12.3	8.0	41.2	5.1
Other Paperboard	5.4	3.4	0.3	5.6	0.2
Paper Packaging	4.2	2.7	0.3	7.1	0.2
Subtotal - Paper	29.0	(18.4)	8.6	(29.7)	(5.5)
Plastics:					
Plastic Containers	2.9	1.8	0.1	3.4	>0.1
Other Plastic Packaging	2.8	1.8	Neg.	0.0	0.0
Subtotal - Plastics	5.7	(3.6)	0.1	(1.8)	(>0.1)
Wood Packaging	2.1	(1.3)	Neg.	(0.0)	(0.0)
Other Miscellaneous Packaging	0.2	(0.1)	Neg.	(0.0)	(0.0)
TOTAL CONTAINERS AND PACKAGING	53.3	(33.8)	10.6	(19.9)	(6.7)
DURABLE GOODS					
Major Appliances	2.8	1.8	0.2	7.1	0.1
Major Appliances	2.8	1.8	0.2	7.1	0.1
Rubber Tires	1.8	1.1	0.1	5.6	>0.1
Other Durables	14.9	9.4	0.1	0.7	>0.1
TOTAL DURABLE GOODS	19.5	(12.4)	0.4	(2.1)	(0.3)
OTHER WASTES[c]					
Food Wastes	12.5	(7.9)	Neg.	(0.0)	(0.0)
Yard Wastes	28.3	(17.9)	Neg.	(0.0)	(0.0)
Miscellaneous Inorganic Wastes	2.6	(1.6)	Neg.	(0.0)	(0.0)
GRAND TOTAL	157.7	100.0	17.0	NA[d]	10.8

[a] () Indicates percentage subtotals for categories.

[b] Neg. = Less than 100,000 tons.

[c] Some of these wastes are composted or otherwise recovered, but this is not estimated here.

[d] NA = Not applicable.

that most of the materials separated were a result of private initiatives since State or local community separation programs were not widespread in 1986. Also, corrugated paper which is usually separated as a result of private commercial activities, accounted for nearly half of the materials separated. Since many municipal and commercial separation/recycling programs have begun since 1986, and since the cost of disposing of MSW has risen, it is probable that the amount of total MSW separated has increased. However, no current nationwide estimates are available.

2.3 REFERENCES

1. U. S. Environmental Protection Agency. Characterization of Municipal Solid Waste in the United States, 1960 to 2000 (Update 1988). EPA/530-SW-88-033. March 1988.

3.0 CASE STUDIES OF FOUR COMMUNITY CURBSIDE MATERIALS SEPARATION PROGRAMS

This section of the report presents case studies of four community curbside materials separation/recycling programs. Each case study contains information on how separation is achieved, the amount and fate of each separated material, enforcement and recordkeeping aspects of the program, and the capital and annual costs of the separation program. The four communities are: Woodbury, New Jersey; Seattle, Washington; Islip, New York; and Rhode Island. Each of these communities uses a different strategy for separating materials from the waste stream. These four communities also represent different geographical areas and a range of populations, and are typical of many other U. S. communities.

3.1 WOODBURY, NEW JERSEY

3.1.1. Materials Separation Program Description

Woodbury, New Jersey, has a population of about 12,000 and is located in Gloucester County in the southwestern part of the State. The community is 80 percent residential consisting of single and two-family homes, and 20 percent commercial/institutional including apartments, commercial establishments, industries, offices, churches, schools, and a hospital. According to Mr. Donald Sanderson, Chairman of the Woodbury Recycling Committee, the New York Times and the Philadelphia Enquirer have deemed Woodbury to be "the typical small U.S.A. town."[1,2]

Materials separation activities in Woodbury were organized in the early 1970's by environmentally-concerned citizens and local community organizations. In 1972, volunteers formed the Woodbury Recycling Committee. From 1970 to 1980, these volunteers, along with the support of the City Public Works Department, organized curbside pick-ups for glass, aluminum, mixed metals, and paper, and established reclamation centers for handling these items. During this period, about 10 to 15 percent of Woodbury's residents participated in recycling.[1,2]

In 1980, the Woodbury Recycling Committee undertook a study to determine which materials in the waste stream could be separated for recovery, what markets were available for these materials, and to design an effective mandatory curbside collection program. This study used available information from the State of New Jersey regarding MSW composition and information obtained by the recycling committee from Woodbury's voluntary recycling efforts. The study estimated that a mandatory materials separation program could reduce the amount of waste being landfilled by about 45 percent. The study also found that while some citizens and organizations were adamantly opposed to mandatory recycling, 60 percent of the population favored such a program. The results of the study and a proposed mandatory recycling program were presented to the Woodbury City Council in late 1980. The City Council narrowly passed a recycling ordinance in December 1980, and the mandatory program became effective in February 1981.[1,2]

Woodbury's initiative was consistent with the State of New Jersey's 1980 plan to work toward 25 percent annual recovery of the State's solid waste by 1985. The State strategy urged communities to formulate their own waste reduction programs, declared a tax surcharge on each ton of waste landfilled, and created a fund to give rebates to communities for each ton of waste material recovered for recycling.[1]

The Woodbury recycling program initially required separation of paper (newspapers and clean white paper separated from cardboard and brown bags), glass by color, aluminum, ferrous metals, and trash, including nonrecoverable materials and yard waste. All items had to be completely segregated in metal or plastic containers supplied by the individual household. Initially, the program had also intended to include separation of food waste, but this requirement was soon abandoned because of strong objection by citizens. Food waste is now included in the trash. In late 1981, the city ordinance was amended to require that yard waste (brush, leaves, and grass clippings) be separated from the trash and placed at curbside in separate containers or bundles. In 1989, separation of plastic containers (i.e., detergent bottles, beverage bottles, and milk containers) was added to the program.[1,2]

Currently, the city collects recyclables at curbside each Monday and Tuesday. Yard waste is picked up on Wednesday, and trash is picked up on

Thursday and Friday. All collection services are provided by the municipality. The recyclables are picked up by two rear-compactor trucks that tow small custom-built compartmentalized trailers. The first truck collects newspaper and white paper together in the compactor section of the truck body. Ferrous metals, nonferrous metals, clear glass, and colored glass are then collected in separate compartments of the trailer towed by the truck. A second rear-compactor truck follows and collects brown cardboard and brown bags in the truck body. Plastics are collected in the trailer pulled by this truck. All types of plastic containers are collected together in a common compartment, and are not separated by resin type.

At the end of their route, the trucks drop off their trailers at an outdoor central reclamation center, which is located behind a shopping center, and then go directly to the market to deliver the paper.[2,3] Glass, metals, and plastics are stored in separate bins at the outdoor reclamation center and are transported to market when each bin is full. The reclamation center is fenced in and is open to the public during certain times of the week. Often, residents take their recyclables directly to the center if they plan to be out of town or if they happen to be shopping in the area.[2,3]

White goods (i.e., large appliances such as stoves and refrigerators) are also collected separately. There is no set schedule for collection of white goods. Residents can either call the city to schedule a pick-up, or they can take them to the reclamation center.[2,3]

Yard waste, except for tree limbs and brush, is collected in compactor trucks or vacuum trucks and transported directly to area farms where it is composted. At the curbside, workers open plastic bags or any other containers containing the yard waste and deposit the yard waste in the truck. Plastic bags are left behind at the curbside. Residents are encouraged to leave a brick or rock nearby, so that the workers can place a weight on the bags, so they will not be blown away in the wind. Tree limbs and brush are picked up separately and taken to a wood chipper operated by the city.[2,3]

Trash is collected by compactor trucks and transported to a landfill. In the near future, all trash will be taken to an MWC, which is currently being tested in the nearby community of West Deptford.[2,3]

The city employs a trained waste inspector who randomly inspects residential or commercial trash bins on trash pick-up days. The inspector has been deputized and has the authority to issue citations for noncompliance with the materials separation ordinance. If the inspector finds recyclable materials in the trash, he attaches a red tag to the trash container which warns the resident that they are in noncompliance and subject to penalty. This tag also gives a telephone number that the resident can call if they need information on how to separate materials to comply with the ordinance. The inspector then records the address of that resident, so that he can reinspect them the following week. Trash collectors do not pick up containers that have been tagged, and the household receives no service for that week. The following week, the inspector first inspects the trash of those who were not in compliance the previous week. If they still have not separated recyclables from their trash, the inspector attaches another red tag and then sends a letter of summons for those persons to appear in court. The judge often issues a verbal warning for the first offense. According to Mr. Sanderson, most persons choose to comply after receiving a verbal warning from the judge. However, some persons who have still not separated recyclables from their trash after receiving a warning from the judge have been ordered to pay fines or perform community service work. Noncompliance with the ordinance carries a maximum $500 fine.[2]

In 1988, the residents and businesses in Woodbury generated a total of 7,697 tons of MSW. Of this amount, a total of 3,229 tons (42 percent) was separated for recovery. Table 3-1 shows a breakdown of the amount of each material separated.[4]

As shown in Table 3-1, separation for Woodbury in 1988 of mixed paper, corrugated paper, glass, aluminum, and ferrous metals totaled 2,113 tons, or 27.5 percent of the total MSW stream. The table also shows that 1,107 tons of yard waste, or 14.3 percent of the total MSW stream was separated for recovery.

In June 1989, Woodbury residents were also required to separate plastic milk containers, soda bottles, and household detergent bottles. Residents must remove and discard metal and plastic caps from these

TABLE 3-1. TOTAL 1988 TONNAGE OF RECOVERABLE MATERIALS COLLECTED IN THE CITY OF WOODBURY[4]

Material	Tons Collected[a]	Percentage of Overall MSW Generated
Newspaper and white paper	822	10.7
Corrugated paper	329	4.3
Glass	492	6.4
Aluminum	9	0.1
Ferrous metals	461	6.0
Total paper, glass, and metals	2,113	27.5
Leaves	393	5.1
Yard debris (grass clippings, etc.)	488	6.3
Brush (bushes, tree limbs, etc.)	226	2.9
Total yard waste	1,107	14.3
Used oil	5	0.06
Total Materials Collected	3,225	41.9
Total MSW Landfilled	4,472	58.1
Total Materials Recovered	3,225	41.9
Total MSW Generated	7,697	100.0

[a] Includes waste from all residences and businesses serviced by the municipality.

containers and place all plastic containers together in one separate collection container. Separation of plastic containers will increase Woodbury's overall MSW reduction rate in the future.[2,3]

As of November 1989, markets were available to accept all of the materials collected by the City of Woodbury's recycling activities.[3] A paper dealer accepts all separated paper and corrugated paper, a glass manufacturer buys all clear and colored glass, a scrap metals dealer buys ferrous and nonferrous metals, a plastics buyer buys all plastic containers, yard waste is composted at local farm sites, and wood chips are used for landscaping local parks and other public facilities. All of these markets are located within a 1-hour hauling distance from the city.[1,2]

Complete records of all materials separation and waste disposal activities are kept by the Woodbury Streets and Utilities Department. The weights of all paper, metal, glass, and plastic materials separated for recovery are obtained when the materials are delivered to the market. At the market, the materials are weighed and a weight slip is issued which documents the amount of material delivered. These weight slips are used by the City of Woodbury to calculate monthly and annual tonnages of each type of material recovered.

City work logs also document the number of truckloads of leaves or yard debris collected and transported to the composting facilities, and the loads of tree limbs and brush taken to the wood chipper. Each truckload of yard waste is not weighed, but the average weight of a truckload of a certain type of yard waste is known. Therefore, the weight of leaves delivered to the composting site can be estimated by multiplying the number of truckloads of leaves by the average weight of a truckload of leaves. The City of Woodbury keeps separate records on the estimated weight of leaves, yard debris, and tree limbs and brush that are separated for recovery. Records for the amount of waste landfilled are also maintained. Trucks hauling waste are weighed on scales when they enter and exit the landfill.[1,2,4]

Complete records and supporting documentation enable the City of Woodbury to be eligible for recycling grants from the State of New Jersey. The grant program provides monetary rebates to municipalities for each ton of waste recovered for recycling. According to the New Jersey Department of Environmental Protection, to apply for recycling rebates, a municipality must submit a standardized application listing the weight of each type of material recovered. The municipality must also provide documentation in the form of: (1) weight slips from the market; (2) letters or other documentation from the market; (3) in the case of yard waste, a work log documenting the type of yard waste collected, the number of truckloads of material delivered to the recovery facility, the method of collection (i.e., vacuumed, compacted, uncompacted), the volume of the truck, and the calculation to estimate the weight of material recovered based on standard volume to weight conversion factors for yard wastes provided by the State.[5]

Recycling is strongly emphasized as a way of life in Woodbury. There is a recycling curriculum in all public schools. Television, radio, and newspaper promotions are common, and the Woodbury Recycling Committee has created educational recycling videos and pamphlets. Revenues from materials sales are used directly to purchase equipment for the recycling program or other public benefit. In such cases, a sign is displayed to show the public that monies from recycling have been used for buying a particular item. For instance, one new truck used to collect recyclables displays a sign reading, "25 percent of the cost of this truck was paid for by recycling funds." According to Mr. Sanderson, recycling in Woodbury began as a grassroots volunteer effort and grew into one of the Nation's most successful programs. He said that the City of Woodbury's recycling accomplishments have created a great source of pride and community spirit for the citizens of Woodbury.[1-3]

Mr. Sanderson added that neighborhood peer pressure helps to increase compliance with the program. Often residents will call the city to report that their neighbors are not separating their recyclables properly. Presently, about 95 percent of the citizens participate in recycling. The remaining 5 percent of the population consists mainly of temporary residents.[2]

3.1.2 Materials Separation Program Costs for Woodbury, New Jersey

This section presents the capital costs, operation and maintenance (O&M) costs, and economic credits experienced by the City of Woodbury for its recycling program in 1988. Some program costs are borne directly by the citizens of Woodbury. For example, the residents are required to provide their own recycling containers and to separate their trash into individual containers, whereas some municipalities provide containers and have separation done by the trash collectors or at a centralized processing facility. In general, the additional cost of containers or labor to separate materials is very small on a per household basis and is not a significant portion of the total program costs. Most households use on-hand containers such as cardboard boxes or old buckets, rather than purchasing new containers.

3.1.2.1 Capital Costs. Capital costs for the Woodbury recycling program include the cost of trucks, trailers, chipping and stumping machines, and drop-off center construction. These costs were annualized by using an interest rate of 10 percent and assuming an equipment life for each item as specified in Table 3-2.

Table 3-2 presents the annualized capital costs for the Woodbury program in 1988 dollars.[6] The major capital costs are for the garbage and diesel trucks, which are used for collecting both recyclables and trash. The unit cost for each truck was multiplied by a fraction of recycling use assigned to that truck based on records of fuel usage for trash collection versus recyclables collection.[4] As shown in the table, total annualized capital costs for the Woodbury materials separation program are $39,365.

3.1.2.2 Operation and Maintenance Costs. Operation and maintenance costs for the Woodbury program include collection and administrative labor, truck fuel/oil, and truck maintenance and insurance expenses. These costs are summarized in Table 3-3. Total O&M costs for 1988 were $215,629.[4,7]

The main O&M cost is labor for the collection of recyclable materials, which comprises almost 60 percent of the total O&M costs. Administrative labor costs, which account for about 9 percent of the O&M costs, include an allowance for a trash inspector's salary. The trash inspector enforces the requirement that recyclables be separated from trash.

The costs of operating and maintaining the trucks account for about 33 percent of the total O&M costs. Truck maintenance and insurance costs were calculated as five times the fuel/oil costs based on International Revenue Service allowances for maintenance and insurance costs as a proportion of total mileage allowance.

Collection of recyclable materials, which occurs the entire year, accounts for about 60 percent of the truck O&M costs. Collection of yard debris and brush accounts for about 23 percent of truck O&M costs, and leaf

TABLE 3-2. WOODBURY MATERIALS SEPARATION PROGRAM CAPITAL COSTS FOR 1988[a]

Item[b]	Quantity[b]	Fraction Used For Recycling	Unit[b] Cost ($)	Total[b] Cost ($)	Year[b] Incurred	Equipment Life (Years)	Capital[c] Recovery Factor	Annual Cost ($/yr)
Vacuum Truck	1	1.00	9,000	9,000	1964	10	0.1627	1,464
Vacuum Truck	1	1.00	9,000	9,000	1970	10	0.1627	1,464
Garbage Trucks	2	0.49	55,000	53,810	1985	10	0.1627	8,757
GMC Diesel Trucks	2	0.49	100,000	97,836	1985	10	0.1627	15,922
Recycling Trailers	2	1.00	15,600	31,200	1984	15	0.1315	4,102
Chipping Machine	1	1.00	17,000	17,000	1985	10	0.1627	2,767
Stumping Machine	1	1.00	19,000	19,000	1985	10	0.1627	3,092
Drop-Off Centers	2	1.00	5,000	10,000	1983	30	0.1061	1,061
Additional Equipment	1	1.00	5,600	5,600	1985	15	0.1315	736

					Total Annualized Capital Costs			39,365

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[a] All costs are presented in 1988 dollars.

[b] Reference 6 provides a listing of the equipment used for recycling, its unit cost, and the year purchased. This information was obtained from a questionnaire completed by the City of Woodbury.

[c] Based on a 10-percent cost of capital.

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TABLE 3-3. WOODBURY MATERIALS SEPARATION PROGRAM OPERATION AND MAINTENANCE COSTS FOR 1988[a,b]

Item	Annual Cost ($/yr)
Collection Labor	125,469
Administrative Labor	19,000
Truck Fuel/Oil	11,860
Truck Maintenance and Insurance	59,300
Total O&M Costs	215,629

[a] References 4 and 7.

[b] All costs are in 1988 dollars.

collection, which only occurs in the fall, accounts for the remaining 17 percent.

3.1.2.3 Program Revenues or Credits. Two sources of credit are available for offsetting the recycling program costs. The first is revenue from the sale of recyclables. As shown in Table 3-4, the City of Woodbury received $41,457 from the sales of recyclables in 1988.[4]

The second source of credit is the avoided landfill charge for the materials separated. This credit is calculated by multiplying the weight of materials not landfilled due to the materials separation times the fee ($49 per ton [$/ton]) that would have been charged if the separated materials had been landfilled. In 1988, 3,225 tons of materials were diverted from the landfill, and the resulting credit for avoided landfill charges was $159,573.[4]

The total annual materials separation credit from these two sources, therefore, was about $200,000 in 1988. Further credits might be assigned for the avoided or delayed cost of buying new landfill area, but this credit was not considered in this study.

3.1.2.4 Net Program Cost. The net program cost is the difference between the annualized capital costs plus total O&M costs and the sales revenues plus avoided landfill charges. All four items for 1988 are summarized in Table 3-5. The total program cost without the credit for avoided landfill fee charges, which reflects actual cost to the city for materials separation services, is approximately $214,000 for 1988. The total program cost with the avoided landfill credit, which reflects the total net cost for the materials separation program, was approximately $54,000 for 1988.

Table 3-5 also presents these costs as $/ton of recyclable material diverted from the landfill. The actual cost to the city of Woodbury for each ton of recyclable material diverted from the landfill was $66/ton. When the avoided landfill credit is included, however, the net cost is reduced to $17/ton of recyclable material diverted from the landfill.

Costs are also presented in Table 3-5 in terms of $/ton of total MSW generated (trash plus recyclables), which is a measure of the amount by which the materials separation program increases the cost of collecting and disposing of each ton of MSW. As shown in the table, when the avoided landfill credit is not included, the increased cost per ton of MSW

TABLE 3-4. WOODBURY MATERIALS SEPARATION PROGRAM CREDITS FOR 1988[a,b]

Item	Annual Cost Credit ($/yr)
Revenue from Sale of Recyclables	41,457
Avoided Landfill Fee[c]	159,573

Total Credits	201,030

[a] Reference 4.

[b] All credits are in 1988 dollars.

[c] Landfill fee for 1988 was $49/ton. Total tonnage avoiding landfilling was 3,225.

TABLE 3-5. WOODBURY MATERIALS SEPARATION TOTAL PROGRAM COST SUMMARY FOR 1988[a]

Weight of Total MSW Generated (tons)[b] = 7,697

Weight of Total Materials Recovered (tons) = 3,225

Total Annualized Capital Costs ($) = 39,365

Total O&M Costs ($) = 215,629

Recycling Revenue ($) = 41,457

Avoided Landfill Fee ($) = 159,573

	Total ($/yr)	$/ton of Total Materials Recovered	$/ton of Total MSW Generated
Total Program Costs (without avoided landfill credit)	213,537	66	28
Net Program Costs (with avoided landfill credit)	53,964	17	7

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[a] References 4, 6, and 7.

[b] Total MSW includes all trash landfilled and all recyclables collected by the city.

collected is $28. When the avoided landfill credit is included, the net increased cost per ton of MSW collected is only about $7.

3.1.3 References for 3.1

1. Source Separation, the Woodbury Way. Booklet prepared by the Woodbury Recycling Committee. City of Woodbury, NJ. 1982.

2. Personal communication between Donald Sanderson, Recycling Chairman, Woodbury, NJ, and Lee Davis, Radian Corporation. October 24, 1989.

3. Information obtained from visit to the City of Woodbury, NJ. Lee Davis, Radian Corporation. November 15, 1989.

4. Records of recyclable materials separated and municipal solid waste landfilled by the City of Woodbury, NJ, in 1988. Records submitted by Herbert Hood, Superintendent, Streets and Utilities Department. Woodbury, NJ. October 20, 1989.

5. Telecon between Joe DeMare, New Jersey Department of Environmental Protection, and Lee Davis, Radian Corporation. October 31, 1989.

6. Beyond 25 Percent: Materials Recovery Comes of Age. The Institute for Local Self-Reliance. April 1989. pp. 23-29.

7. Telecon between Raymond Jack, City of Woodbury, NJ, and Lee Davis, Radian Corporation. November 30, 1989.

3.2 SEATTLE, WASHINGTON

3.2.1 Materials Separation Program Description

The City of Seattle, Washington (population 500,000) has been achieving increasing rates of materials separation since 1981 when the city set a variable rate structure for trash container collection. The rate charged per household depended upon the number of trash containers collected per week. This incentive, along with strong participation from private citizens, private community organizations, businesses, and government, helped to create a large network of private materials separation activities. Much of this network consisted of both profit and nonprofit drop-off or buy-back centers where residents delivered recyclable materials. From 1981 to 1988, the average residential subscription rate for trash pick-up dropped from 3.5 containers per household to 1.4 containers per household.[1]

In 1987, faced with dwindling landfill space and local opposition to plans for an MWC, the City of Seattle began a major study to determine the composition of municipal waste separated, existing rates of recycling, and alternatives to further increase recycling activities. In this study, computer models were used to evaluate the costs and effects of six waste management scenarios involving 21 different recycling programs and 13 disposal options including near and distant landfilling, composting, and various types of MWC's.[2] As a result of this study, the City of Seattle adopted a plan which includes a goal of recycling (including composting) 60 percent by weight of the city's waste by 1998. The city began phasing in new programs in early 1988 which will work toward achieving this waste reduction goal.[1]

To provide a clear picture of the evolution of recycling activities in Seattle, it is necessary to first examine the rates of private materials separation achieved before the city's 1988 initiative, and to then examine the additional separation achieved as a result of recent programs directed by the Seattle Solid Waste Utility. Materials separation activities which take place independent of city-directed programs are referred to below as "private" materials separation, and those which are a direct result of new city programs are referred to as "utility-initiated" materials separation.

Table 3-6 shows a breakdown of the amount and composition of waste generated in 1987 by the residential and commercial sectors including

TABLE 3-6. COMPOSITION AND AMOUNT OF MSW GENERATED IN SEATTLE BY THE RESIDENTIAL AND COMMERCIAL SECTORS IN 1987[2]

Material	Residential		Commercial	
	Tons Generated	%	Tons Generated	%
Newspaper	36,808	14.9	22,606	5.1
Corrugated/Kraft	10,737	4.4	92,353	21.0
High Grade Paper	2,908	1.2	67,788	15.4
Mixed Paper	26,953	10.9	28,914	6.6
Other Paper	13,127	5.3	32,026	7.3
Plastic	10,062	4.1	23,113	5.3
Yard Waste	51,147	20.7	33,418	7.6
Wood	5,429	2.2	22,421	5.1
Food Waste	16,083	6.5	31,206	7.1
Organics	9,047	3.7	19,409	4.4
Beverage Glass	17,031	6.9	6,324	1.4
Container Glass	8,528	3.5	4,985	1.1
Other Glass	5,719	2.3	7,208	1.6
Food Cans	4,704	1.9	4,178	0.9
Other Ferrous Metals	8,289	3.4	13,176	3.0
Aluminum Beverage	3,603	1.5	992	0.2
Other Aluminum	938	0.4	1,391	0.3
Other Nonferrous Metals	662	0.3	3,127	0.7
Construction Debris	5,380	2.2	13,624	3.1
Miscellaneous	9,543	3.9	11,782	2.7
	246,698	100.2[a]	440,041	99.9[a]

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[a] Totals do not equal 100.0 percent due to rounding

manufacturing, wholesale and retail trade, offices, eating establishments, schools, hospitals, government offices, and all other nonresidential waste.

Table 3-7 shows the tonnage and percent of each of these materials separated for recovery in 1987 through private initiatives encouraged through the 1981 implementation of the variable rate structure. Also, it was cheaper for commercial businesses to sell recyclable materials rather than to landfill them in 1987, especially since Seattle has good markets for most recyclable materials. The city obtained the data in Table 3-7 from private waste collectors, waste processors, and local organizations responsible for drop-off and buy-back centers.[3] Newspapers comprised over 50 percent of the weight of materials recovery by the residential sector. Glass, ferrous metals, aluminum, and miscellaneous items accounted for the remainder of the items removed. Table 3-7 also shows that paper products, especially corrugated paper and high grade paper, comprised over 85 percent of commercial separation with glass, ferrous metals, aluminum, and miscellaneous items comprising the rest.

Table 3-8 provides a summary of the total amounts of MSW generated and amounts separated by the residential and commercial sectors in 1987. A total of 18.0 percent of the residential waste stream and 28.6 percent of the commercial waste stream was separated for recovery. The total rate of separation in Seattle for 1987 was 24.8 percent. These values reflect the rates of materials separation achieved in Seattle prior to the city's aggressive 1988 materials separation initiatives.

The City of Seattle has been phasing in its new materials separation/recycling programs since early 1988.[1] These programs include the following:

- Revised Rate Schedule - The monthly curbside collection cost for one 30-gallon trash can is $13.75 (higher rates apply for backdoor collection). Each additional can costs $9.00. No fee is charged for curbside collection of separate containers of newspaper, mixed paper, cardboard, glass, tin cans, and aluminum. Those residents that generate little trash and/or separate most of the listed materials may use a smaller 19-gallon trash can and pay only $10.70 per month. Trash pick-up is contracted by

TABLE 3-7. COMPOSITION AND AMOUNT OF MSW SEPARATED THROUGH PRIVATE INITIATIVES IN SEATTLE BY THE RESIDENTIAL AND COMMERCIAL SECTORS IN 1987[2]

Material	Residential Tons Separated	%	Commercial Tons Separated	%
Newspaper	25,661	57.8	10,999	8.7
Corrugated/Kraft	0	0.0	52,304	41.7
High Grade Paper	0	0.0	43,612	34.7
Mixed Paper	0	0.0	3,455	2.7
Other Paper	0	0.0	0	0.0
Plastic	0	0.0	0	0.0
Yard Waste	0	0.0	0	0.0
Wood	0	0.0	0	0.0
Food Waste	0	0.0	0	0.0
Organics	0	0.0	0	0.0
Beverage Glass	7,284	16.4	2,397	1.9
Container Glass	3,593	8.1	1,198	1.0
Other Glass	0	0.0	0	0.0
Food Cans	83	0.2	241	0.2
Other Ferrous Metals	3,309	7.4	2,211	1.8
Aluminum Beverage	1,499	3.4	225	0.2
Other Aluminum	0	0.0	0	0.0
Other Nonferrous Metals	0	0.0	0	0.0
Construction Debris	0	0.0	0	0.0
Miscellaneous	3,000	6.8	8,985	7.1
	44,429	100.1[a]	125,627	100.0

[a] Total does not equal 100.0 percent due to rounding

TABLE 3-8. TOTAL WASTE GENERATED AND TOTAL MATERIALS SEPARATED IN SEATTLE IN 1987[2]

	Residential Sector	Commercial Sector	Total
Total Waste Generated	246,698	440,041	686,739
Total Materials Separated	44,429	125,627	170,056
Percent Separated	18.0	28.6	24.8

competitive bidding to three private companies who issue specially marked trash cans to residents. The number and size of cans issued depends on the service requested and paid for by the resident. Only these specially marked cans are collected. Residents pay collection fees to the city.

- Curbside Collection Program - Curbside collection service for recyclable materials was offered to all single family and multi-family units up to four-plexes beginning in February 1988. The city contracted two private companies by competitive bidding to provide collection of recyclable materials, one on the north side of the city and one on the south side. On the north side, residents are asked to separate paper, glass, and metals in three separate compartments of a stackable container. On the south side, residents put all recyclable items in one container, and these commingled materials are later separated at a materials recovery facility (MRF). The city pays these companies about $48/ton of recyclables collected. The companies bear responsibility for sales of the materials collected and retain the profits. The materials separation contracts have a 5-year duration.

- Mandatory Yard Waste Collection - The city began mandatory yard waste separation on January 1, 1989. While the mandatory separation is not enforced at the household level, haulers are forbidden from delivering waste to a landfill which contains yard waste. For a monthly fee of $2.00 per household, up to 20 cans, bags, or bundles of yard waste per month will be collected from each residence. The city contracted three companies by competitive bidding to provide yard waste collection services. The yard waste is then composted at a new, privately-owned centralized composting facility. The city also encourages backyard composting with free training kits. If a household elects to use backyard composting rather than curbside collection of yard waste, the monthly fee does not have to be paid. The city believes that the $2.00 per month charge is low enough to encourage participation in the yard waste collection program, but high enough to not discourage backyard composting.

Since Seattle began its new curbside collection program in early 1988, the city has diverted an additional 3.4 percent of the total waste stream through the collection of newspapers, mixed paper, glass, tin cans, and aluminum. This amount is in addition to the amount achieved in 1987 (Tables 3-7 and 3-8). According to Ms. Jennifer Bagby, Economist for the Seattle Solid Waste Utility, the new curbside program actually diverts 5.8 percent of the total waste stream, but only 3.4 percent is new materials separation since some of the materials that were previously taken to drop-off centers are now being placed in curbside recycling bins.[3]

According to Ms. Bagby, data for private materials separation for 1988 have not yet been compiled.[3] As an alternative, the overall MSW materials separation rate for 1988 ~~can~~ be estimated by adding the overall MSW reduction achieved in 1987 through private materials separation to the additional reduction achieved through the utility-initiated programs in 1988. This calculation assumes the rate of private materials separation in 1988 is the same as for 1987 with the exception of materials replaced by utility-initiated curbside programs. By adding the 24.8 percent overall MSW reduction achieved through private initiatives, and the additional 3.4 percent achieved through utility-initiated curbside programs, the overall MSW reduction for the City of Seattle is calculated to be 28.2 percent for 1988.

In addition, the yard waste composting program which started in January 1989 is diverting about 5.8 percent of the total waste stream. No yard waste was separated prior to 1989. The addition of yard waste separation is expected to increase the overall rate of MSW reduction to over 34 percent for 1989.[3]

The two private waste haulers under contract with the city to provide curbside collection for recyclable materials each own and operate an MRF. At these facilities, a combination of manual and mechanical methods are used to sort the recyclable materials. The private waste haulers have the responsibility of marketing the materials that they collect and separate. Local markets are available for all of the newspaper, glass, and metals collected. However, there is no local market for mixed paper. All mixed paper is exported to markets in Asia.[4] The exporting of mixed paper is feasible since Seattle is a port city.

As discussed above, yard waste pick-up is contracted to three private haulers. These haulers collect the yard waste at curbside and deliver it to a new, privately-owned and operated composting facility. At the facility, the yard waste is shredded and piled into windrows. The finished compost product will be sold as a soil conditioner or used as landfill cover.[1]

Nonrecoverable trash is currently disposed of in a county-owned landfill. In the future, Seattle plans to send this waste by railcar to distant landfills in eastern Washington or Oregon.[1]

The City of Seattle is putting a great amount of effort into community education and promotion in its quest to reach a goal of reducing the overall weight of MSW by 60 percent by 1998. Waste reduction education programs have been integrated into all public school curricula in grades K through 12. Information on waste reduction techniques is distributed to the general public through newspaper, radio, and television, and through educational packets mailed to individual households. Common themes include backyard composting of food and yard waste, avoiding products with excessive packaging, buying goods containing recycled materials, and buying durable products. In addition, the city has an automated telephone service with over 100 recorded messages to address all aspects of the waste reduction and recycling program. About 75 percent of Seattle residents currently participate in the curbside programs.

The Seattle Solid Waste Utility is also attempting to initiate an apartment recycling program to serve multi-unit residential buildings since the present curbside program only serves units up to four-plexes. This program will inform apartment residents and owners on how to separate recyclable materials and will contract private haulers for collection services. Under this program, the city would pay private haulers for each ton of recyclable materials diverted from the waste stream. The city has had difficulty in getting haulers to participate in this program and is currently restructuring the program to make it more attractive.[1]

The city is also considering a differential rate structure for trash collection from commercial businesses similar to the one currently in place for residences. This would encourage more waste reduction and recycling activities by commercial businesses by giving them an additional financial incentive.

Seattle's goal for 1998 is to reduce the total MSW stream by about 26 percent through its utility-initiated programs such as curbside recyclables separation, curbside yard waste collection, apartment recyclables separation, and backyard composting. Seattle also expects to increase private separation and recycling from its current rate of 24 percent to about 34 percent of the total waste stream. This could be facilitated by adopting a differential rate structure for collection of waste and recyclables from commercial businesses. With 60 percent of the waste stream separated for recovery, only 40 percent would have to be disposed of in distant landfills.[1]

3.2.2 Materials Separation Program Costs for Seattle, Washington

As discussed in the above section, citizens, private organizations, and businesses in the City of Seattle successfully separated a total of 170,056 tons of recyclable materials (24.8 percent of the total MSW generated) in 1987. Commercial establishments accounted for 125,627 tons of the separated materials, while households accounted for 44,429 tons.[2] Materials separation activities in Seattle are motivated by several factors: (1) the variable rate structure for residential collection discussed in Section 4.2.1 encouraging household source separation; (2) the cost effectiveness for businesses to separate and sell recyclable materials, such as cardboard, rather than to landfill them; (3) well-established and stable markets for recyclable materials in the Seattle area; and (4) the relatively strong environmental ethic of the Seattle citizenry. Costs of private materials separation activities are borne primarily by the individual citizens, community organizations, or businesses who separate the recyclable materials from MSW and transport them to market.[5] The City of Seattle municipal government bears little or no cost for private materials separation.

This section presents information on direct and indirect costs and benefits associated with the implementation and administration of Seattle's voluntary curbside recycling program. While the Solid Waste Utility is implementing or is planning to implement other materials separation programs over the next 2 to 3 years, only the voluntary curbside recycling program has been demonstrated for a full year. Therefore, costs are presented for the voluntary curbside recycling program for 1987, the year the program was conceived and planned, 1988, the first full year of the program, and cost projections are presented for 1989 through 1991. All costs and benefits are expressed in 1988 dollars.

3.2.2.1 Overview of Costs and Credits Considered. The City of Seattle's costs for the curbside recyclables collection program includes administrative costs, educational and promotional costs, and direct costs in the form of payments to the contractors for each ton of recyclable material collected. Residential curbside recyclables collection services and materials processing are contracted by the City of Seattle to private haulers through competitive bidding. The City of Seattle pays selected contract haulers $48/ton of recyclable materials collected, but incurs no capital cost for this program since all of the collection vehicles and processing equipment are owned by the private contractors.[1,2]

The $48/ton received by the private contractors is assumed to cover the contractors' capital costs; all operating and maintenance costs relating to collection activities, transportation, processing, and marketing of the materials collected; and the contractors' profit. The contractors also receive the revenue obtained from recyclable materials sales.

The city receives no revenue from sales of the recyclables, but the city does benefit from the diversion of the collected materials from the landfill. Landfill avoidance produces credits that help offset costs for the separation program. Credits include reduced transportation costs, the costs of transporting materials to the landfill being higher than transporting recyclables to the processing facilities, and elimination of charges for landfilling. In addition, landfill avoidance extends the life of present landfills and delays some of the costs associated with the siting and construction of new landfills.

3.2.2.2 Annual Costs and Credits. Table 3-9 presents estimated costs and credits for the curbside recyclables collection program for the years 1987 through 1991.[6] All costs and credits are presented in 1988 dollars. In 1987, the year prior to start-up of the program, total costs for administration, education, and promotion were $1,018,320. These

TABLE 3-9. ESTIMATED COSTS AND BENEFITS OF SEATTLE'S RESIDENTIAL CURBSIDE RECYCLABLES COLLECTION PROGRAM[a,b]

Cost	Year 1987	 1988	 1989	 1990	 1991
Administration ($)	383,600	383,600	287,780	290,680	186,180
Education and Promotion ($)	634,720	612,200	397,820	397,820	150,000
Payments to Contractors ($)[c]	0	1,173,354	1,960,000	2,131,500	2,449,000
Total Cost ($)	1,018,320	2,169,154	2,645,600	2,820,000	2,785,180
Tonnage Information					
Total MSW Collected by Utility (tons)[d]	516,412	535,877	613,901	617,508	623,702
Recyclables Collected by Utility Program (tons)[e]	0	23,946	40,000	43,500	50,600
Recyclables Diverted from Landfill (tons)	0	10,020	24,565	27,794	34,300
Total Cost per Ton of Recyclables Collected ($/ton)	N/A	91	66	65	56
Benefits					
Avoided Cost per ton of Recyclables Diverted from Landfill ($/ton)[f]	N/A	77.00	77.00	85.50	85.50
Total Benefit ($)	0	771,540	1,891,505	2,376,387	2,932,650
Net Cost ($)	1,018,320	1,397,614	754,095	443,613	-147,470
Net Cost per Ton of Recyclables Diverted ($/ton)	N/A	139	31	16	-4.30
Net Cost per ton of Total MSW Collected ($/ton)	1.97	2.61	1.23	0.72	-0.24

[a] Reference 6
[b] Costs and benefits are in 1988 dollars.
[c] Forty-eight dollars paid to contractors for each ton of recyclable material collected.
[d] Total MSW includes all trash and recyclables collected by the Seattle Solid Waste Utility.
[e] Does not include recyclables collected by private initiatives.
[f] Includes $54/ton avoided transportation cost and $23/ton avoided landfill charge for 1987-89. For 1990-91, landfill charges are expected to be $31.50/ton.

expenditures were used for planning and preparing the program for start-up. No recyclables were collected, and no credits were realized during 1987.

In 1988, the first year of the program, 23,946 tons of recyclable materials, or 3.4 percent of the total waste stream, were collected at the curbside. Total estimated annual costs were $2,169,154. About half of this cost was paid to contractors for recyclables collection and processing services, and the remaining half was spent on administration, education, and promotion. Total cost to the City of Seattle per ton of recyclable materials collected was about $91.

The utility conservatively estimates that of the 23,946 tons of recyclables collected during the first year of the curbside program, only 10,020 tons (42 percent) was diverted from the landfill as a direct result of the program, since many of the recyclables collected would have been recycled through private initiatives if the program were not in place. Therefore, the Seattle Solid Waste Utility calculates program credits by multiplying the tons of material diverted from the landfill as a result of the program by the cost of landfilling a ton of materials. Total estimated credits for 1988 were $771,540.

Net costs are a measure of the cost of the recycling program versus the cost of landfill disposal. Net costs are calculated by subtracting total program credits from the total program costs. In 1988, total costs were higher than total credits, and net costs were $1,397,614. The net cost to the City of Seattle per ton of recyclable material diverted from the landfill was about $139. The net cost increase per ton of total MSW collected by the utility as a result of the program, including trash and recyclables, was about $2.61. This is a measure of the cost by which the materials separation program raises the average cost of collecting and disposing of each ton of MSW.

In the years following 1988, it is projected that administrative, educational, and promotional costs will decrease as the program becomes more established. It is also projected that collections of recyclable materials will increase due to higher participation rates and additional recyclable material types being separated.[2]

As shown in Table 3-9, in 1991, 5 years after program inception, it is estimated that the total cost to the City of Seattle for recyclables collection and processing will drop to about $56/ton. The table also shows that 1991 is the first year in which total program benefits are expected to exceed total program costs. In 1991, net costs are projected to be -$147,470, which equates to a credit (cost reduction) of $4.30/ton of recyclable materials diverted from the landfill and a credit of $0.24/ton of total MSW collected by the Utility.

3.2.3 References for Section 3.2

1. Parker, Lorie. Seattle's Road to Recovery. Biocycle. June 1989. pp. 29-31.
2. Final Environmental Impact Statement - Waste Reduction Recycling, and Disposal Alternatives. Recycling Potential Assessment and Waste Stream Forecast. Volume 2. Seattle Solid Waste Utility, Seattle, WA. July 1988.
3. Telecon between Jennifer Bagby, Solid Waste Utility, Seattle, WA, and Lee Davis, Radian Corporation. November 7, 1989.
4. Beyond 25 Percent: Materials Recovery Comes of Age. The Institute for Local Self-Reliance. April 1989. pp. 111-119.
5. Telecon between Jennifer Bagby, Solid Waste Utility, Seattle, WA, and Lee Davis, Radian Corporation. November 29 1989.
6. Cost information submitted on computer disk by Jennifer Bagby, Solid Waste Utility, Seattle, WA, to Lee Davis, Radian Corporation. December 7, 1989.

3.3 ISLIP, NEW YORK

3.3.1 Materials Separation Program Description

The Town of Islip (population 300,000) is located in Suffolk County on Long Island, New York. Islip has one of the oldest and largest materials separation programs in the United States. The town began their separation program in 1978 by operating drop-off bins at the landfill where citizens could bring recyclable materials. In 1980, the State of New York ordered the town to initiate a source separation program as a condition for obtaining approval to continue operating its landfill.[1]

Islip was the source of the infamous "garbage barge" which in 1987 wandered down the east coast of the United States to the Caribbean, and back to New York without finding a place to unload its cargo. Since that episode, the town has placed an even greater emphasis on materials separation and recycling.

In 1987, to gain better control of its materials separation program, the town divided itself into 70 garbage districts. Trash and recyclables collection contracts were bid out to private waste haulers for 60 of these districts. The town services the remaining 10 districts. The collection contracts require that the haulers provide separate curbside collection of commingled recyclable materials, yard waste, and trash. Under the contract, all materials collected must be delivered to one of four facilities operated by the Town of Islip: the MRF, the composting facility, the landfill, or the MWC which is currently undergoing start-up testing.[2,3]

Haulers are given an economic incentive to participate. The tipping fee for waste delivered to the landfill or the MWC is $40/ton, while the tipping fee for recyclables delivered to the MRF and yard waste taken to the composting facility is $18/ton. Currently, 16 haulers service the 60 garbage districts.[2,3]

The town's materials separation and recycling program is called WRAP ("We Recycle America and Proudly"). In 1987, all residences were issued 20-gallon plastic WRAP containers for collecting recyclables. All residences are required to separate all paper, glass, aluminum, and tin cans from the rest of their trash and place them together in WRAP pails. The WRAP pails are collected weekly on Wednesday and transported to the MRF for processing.[2,3]

Residences are also required to separate yard waste. Yard waste may be placed at curbside in plastic bags, boxes, or any other type of container. Yard waste is collected weekly on Saturday, Monday, or Tuesday. depending on the location of the district The yard waste is transported directly to the composting facility.[2,3]

The town employs inspectors who randomly inspect residential trash to check for compliance with the program. If recyclable items are present in the trash, the container is tagged with a warning, and that container is not picked up for that week. Continued noncompliance could result in a fine of up to $250; however, few fines are levied.[3]

Apartment complexes and commercial businesses are not covered under the mandatory WRAP program, but, commercial businesses are required to separate cardboard. Separation and transportation of the cardboard is the responsibility of the individual business. The business can either sell it to a private buyer or deliver it to the MRF. If a hauler delivers commercial waste containing a noticeable amount of cardboard to the landfill or MWC, the whole truckload of waste may be rejected. This produces a strong incentive to promote separation of cardboard.[3]

Recyclable materials collected from residential WRAP containers are processed at the MRF. The MRF is located in a building which used to house an MWC. The MWC was shut down in 1978, and the MRF began operation in 1981. Commingled paper, glass, and metals are dumped by the collection trucks into a large pit. Although all materials are delivered to the MRF on Wednesday, it takes several days to process the 600 to 700 tons of commingled materials delivered each week.[3]

At the MRF, the commingled materials are fed by crane to a hopper which discharges into a large rotating trommel fitted with 8-inch holes. Small paper, glass, and metal cans pass through the holes and onto a conveyor while the larger items (e.g., newspapers, cardboard) continue through the trommel. The smaller fraction proceeds through a magnetic separator where ferrous cans are removed. The small fraction is then conveyed past handpickers who manually separate glass (by color) and aluminum cans. The remainder of the small fraction, which consists mostly of small mixed paper and broken glass, is discharged into a large waste container for disposal. About 15 percent of the glass delivered to the facility is broken during transportation and processing and is not recovered.[3]

The large fraction which passes through the trammel is primarily composed of newspapers and cardboard. This fraction is conveyed past a second group of handpickers who manually remove the cardboard and materials which are considered contaminants in the newspaper fraction such as glossy papers, magazines, and telephone books. The newspapers and cardboard are recovered while the contaminants are disposed along with the mixed paper from the small fraction.

The waste handling equipment at the MRF is largely makeshift, and much of it has been fabricated from scrap materials. The facility is also understaffed. The town has had difficulty in employing a sufficient number of handpickers. While management believes that about 18 handpickers are needed to provide an adequate level of separation, often only about 15 handpickers are employed at a given time. The rate of absenteeism among these employees is also high, and often the facility operates with as few as 10 handpickers.[3]

About 80 percent of the materials delivered to the MRF are currently being marketed. The remaining 20 percent, mostly mixed paper and broken glass, is disposed of.[3] The glass is landfilled, and the mixed paper is disposed of in the landfill or the MWC. The program was initially set up to include separation of all types of paper since there was a market for mixed paper at the time the program began. Now that the paper market has weakened, the Town of Islip has chosen to dispose of mixed papers separated at the MRF rather than to redirect residents to remove mixed papers from their WRAP containers. Town officials said that it is difficult to change policies regarding the types of items that should be separated once residents become accustomed to separating certain items. Also, the town is hopeful that the market for mixed paper will improve in the future.

Glass, newspapers, and cardboard are transported to market in New York City. Tin cans are taken to a detinning facility in Pennsylvania, and white goods and other mixed ferrous materials are taken to a nearby scrap dealer. Aluminum cans are sold to a local buyer.[3]

All yard waste is transported to a 39-acre composting facility which opened in September 1988. At the facility, all leaves, grass clippings, and brush are shredded and then screened to remove pieces of plastic bags.

Leaves collected in the fall are piled in windrows and stored until spring and summer when they can be mixed with grass clippings. Leaves alone compost very slowly because of a lack of nitrogen; however, when mixed with grass clippings, the mixture breaks down much faster. At the Islip facility, wood chips are added to the leaf and grass mixture to provide bulking and aeration. This mixture is piled into windrows which are about 10 feet (ft) wide, 8 ft high, and 100 ft long. The windrows are periodically turned by a turning machine. The materials break down into compost within 6 to 8 weeks. The compost is then piled in large piles to cure for several months. After curing, the compost is screened again to remove wood chips and any residual plastic. The resulting compost is available free to residents who haul it away for use in gardening or landscaping. Currently, the demand far exceeds the supply.[3]

The Town of Islip maintains records on the weights of all materials delivered to each of its waste management facilities. Scale houses are located at the MRF, the composting facility, the landfill, and the MWC. Trucks are weighed as they enter and exit the facilities, and the resulting weight difference is reported as the amount of material received. Trucks transporting separated recyclable materials from the MRF to the market are also weighed. All weights are entered into a central computer data base which computes the total amount of materials collected, the amount of materials separated for recovery, and the amount of waste disposed.[3]

Table 3-10 shows the total weights of all materials collected by the Town of Islip and a breakdown of each material that was separated for recovery for 1988. A total of 23,715 tons were recovered at the MRF and 32,633 tons at the composting facility. Prior to September 1988, yard waste was composted at an older facility which had limited capacity and did not have scales. Therefore, the Town of Islip estimated the weight of yard waste from a record of the number of truckloads of yard waste delivered and an estimate of the average weight of each load. The new composting facility opened in September 1988, and scales were obtained in April 1989. In the future, an accurate weight of yard waste composted will be obtained.[4,5]

TABLE 3-10. WEIGHTS OF MATERIALS SEPARATED FOR RECOVERY THROUGH ISLIP CURBSIDE PROGRAMS FOR 1988[4,5]

Material	Tons Separated
Newspaper	18,192
Cardboard	3,762
White goods and other large ferrous items	869
Tin cans	534
Glass	332
Aluminum	26
Total Materials Collected Through WRAP Program	23,715
Yard Waste Delivered to Composting Facility	32,633
Total Materials Separated Through Curbside Programs	56,348

Table 3-11 gives a breakdown of all waste flows tracked by the Town of Islip and includes an estimate of the weight of beverage containers returned through the New York State container deposit/return program. According to Mr. Joe Phillips of the New York State Department of Environmental Conservation, about 5 percent of the MSW in the State is recovered through the beverage container deposit/return program.[6] As shown in the table, 5.7 percent of the total MSW stream was separated for recovery at the MRF, 7.8 percent was delivered to the composting facility, and 6.0 percent was separated by private commercial businesses. The total MSW reduction achieved for the Town of Islip in 1988 is calculated to be 24.5 percent.

The values reported in Table 3-11 reflect weights reported by the Town of Islip from their materials separation programs, an estimate obtained from the State of New York regarding beverage container returns, and private commercial materials separation which occurred independent of these two programs. According to Ms. Elizabeth Gallagher, Commissioner at the Islip Department of Environmental Control, many commercial businesses bail their waste cardboard and sell it to private buyers. Some of these businesses submit records of the amount of cardboard or other materials separated for recovery, but many do not. Also, the records that are sent to the town are often poorly documented. Table 3-11 includes 25,000 tons of privately separated commercial waste. This value is the town's "best estimate" from the available records.[7]

Since scales were installed at the new composting facility in April 1989, records show that 13.6 percent of the total waste stream is being diverted through yard waste composting. While the data are not complete for the entire year, it is expected that over 60,000 tons will be composted for 1989. Therefore, in the future it is likely that the Town of Islip would achieve a higher rate of yard waste separation. This would result in the town achieving over 25 percent MSW reduction.[3]

In addition, plastic containers have recently been added to the list of materials separated for recovery through the curbside WRAP program. This will increase the rate of overall MSW reduction in the future.[2]

Currently, about 95 percent of residences in Islip participate in the materials separation programs. The town avidly promotes its programs in its public schools and through the local media. Educational programs

TABLE 3-11. TOTAL MATERIALS SEPARATED FOR RECOVERY, TOTAL MATERIALS COLLECTED, AND PERCENT RECOVERED IN THE TOWN OF ISLIP FOR 1988[4,5]

	Tons	Percent of Total MSW Generated
Total MSW Generated[a]	417,620	100.0
Total MSW Disposed in Landfill	315,272	75.5
Total Materials Separated for Recovery at the MRF	23,715	5.7
Total Materials Delivered to the Composting Facility	32,633	7.8
Estimated Weight of Beverage Containers Separated through State Container Deposit Program	21,000	5.0
Total Weight of Materials Separated by Private Commercial Businesses	25,000	6.0
Total Materials Separated for Recovery	102,348	24.5

[a] Includes 396,620 tons received at landfill, MRF, and composting facility plus 21,000 tons estimated through beverage container return.

called "WRAP Sessions" for grades K through 6 include programs to instruct children in recycling and the importance of responsible waste management.[2]

The town also promotes a weekly WRAP contest as an incentive for citizens to separate recyclables from their waste. Weekly, a list of 20 names is randomly generated from a computerized list of homeowners. If they are in compliance, they receive a free dinner for two donated by a local radio station. If they are not in compliance, the inspector leaves a notice of prize eligibility stating that they would have received a free dinner if they had been in compliance. The notice also states that the inspector will check for compliance again in 60 days. If the homeowner is in compliance at that time, they receive a second prize such as a recycling T-shirt or mug. Those residents who demonstrate compliance are also eligible for a $1,000 annual grand prize.[2]

The town sends out quarterly newsletters to all residents which provide current information on the materials separation programs. Public service announcements through the local newspapers and the television and radio stations are also common. In addition, the town created a special WRAP telephone hotline that residents can call to get up-to-date information.[2]

Construction is currently underway on a new $10 million MRF capable of processing up to 3,000 tons of commingled recyclables per week. The new facility, which is expected to begin operation in late 1990 or early 1991, will include mechanical and manual sorting methods for processing the waste. The new facility will have adequate capacity to handle the amount of recyclables to be generated in Islip in coming years, and town officials expect it to be more efficient than the present facility.[3]

Also, a new 500 ton per day (tpd) MWC has been constructed in Islip and is currently operating while start-up tests are being conducted. The MWC consists of two 250 tpd rotary waterwall combustors. Much of the nonrecoverable waste from Islip is being diverted from the landfill and is now being combusted for electrical generation.[3]

3.3.2 Materials Separation Program Costs for Islip, New York

This section presents the estimated capital costs, O&M costs, and economic credits estimated for the Town of Islip materials separation programs for 1990. Materials separation program costs include costs for both the WRAP program and the yard waste collection and composting programs.

3.3.2.1 Capital Costs. Capital costs for the WRAP program include equipment for the presently operating MRF, construction and equipment for the new MRF currently being constructed, trucks which haul recyclables to market, and WRAP pails issued to households. Capital costs for the yard waste program include construction and equipment costs for the composting facility. The Town of Islip also owns trucks which provide trash, recyclables, and yard waste collection services for 10 of the town's 70 waste districts. The capital costs for these trucks are not available and are not included in this analysis, but it is roughly estimated that this cost could increase the annualized capital cost by about 5 to 10 percent. Table 3-12 presents the annualized capital costs for the WRAP Program and the yard waste program in 1990 dollars.[1,2,8] These costs were annualized by using an interest rate of 10 percent and assuming an equipment life for each item as specified in Table 3-12. As shown in the table, total annualized capital costs for the Islip materials separation program are about $2 million. Almost 70 percent of this cost is for the new MRF.

3.3.2.2 Operation and Maintenance Costs. Operation and maintenance costs for Islip materials separation programs are broken down into the following categories: administration; education and promotion; labor at the MRF; all other O&M costs at the MRF (taxes, insurance, utilities, and maintenance materials); labor at the composting facility, all other O&M costs at the composting facility (taxes, insurance, utilities, and maintenance materials); and payments to private haulers for recyclables and yard waste collection services they provide to 60 waste districts. The labor and other O&M costs for collection services for the remaining 10 districts serviced by the town are not available and are not included in this analysis. However, if the costs per district were similar to the fees paid to private haulers, this cost would increase the O&M cost by about $800,000, or about 10 percent. Operation and maintenance costs are summarized in Table 3-13. The total estimated O&M costs for 1990 are about $8.4 million.[8,9,10]

The main O&M cost is for recyclables and yard waste collection services provided by private haulers, which accounts for almost 60 percent

TABLE 3-12. ISLIP MATERIALS SEPARATION PROGRAM CAPITAL COSTS FOR 1990[a]

Item	Total Cost	Year Incurred	Life (years)	Capital[b] Recovery Factor	Annual Cost ($)
Equipment at present MRF[c]	169,000	1987	4	0.3155	70,962
New MRF[d]	10,000,000	1988	20	0.1175	1,292,056
Composting Facility[d]	2,500,000	1989	35	0.1037	313,661
WRAP Containers[e] (initial distribution)	750,000	1987	10	0.1627	162,461
Replacement WRAP Containers[e]	50,000	1988	10	0.1627	9,846
Trucks for Hauling Recyclables to Market[f]	228,000	1989	7	0.2054	51,516
TOTAL ANNUALIZED CAPITAL COSTS					1,900,502[g]

[a] All costs are in 1990 dollars.
[b] Based on a 10 percent cost of capital.
[c] References 1 and 9.
[d] References 2 and 9.
[e] Reference 7.
[f] Reference 9.
[g] Does not include cost of existing trucks that collect MSW, recyclables, and yard waste from 10 waste districts since capital costs were not available.

TABLE 3-13. ISLIP MATERIALS SEPARATION PROGRAM OPERATION AND MAINTENANCE COSTS FOR 1990[a,b]

Item	Annual Cost ($/yr)
MRF Labor	1,600,000
All Other MRF O&M (taxes, insurance, utilities, and maintenance materials)	289,000
Composting Facility Labor	670,000
All Other Composting Facility O&M (i.e., taxes, insurance, utilities, and maintenance materials)	334,000
Educational and Promotional Costs	268,000
Administrative Costs	175,000
Payments to Private Haulers for Collection Services	5,000,000
TOTAL O&M COSTS	8,336,000[c]

[a] All costs are in 1990 dollars.

[b] References 8-10.

[c] This does not include the labor and other collection service costs for the 10 districts where MSW, recyclables, and yard waste are collected by the town rather than by private haulers.

of the total O&M costs. Labor for separating the commingled recyclables at the MRF and for hauling the separated materials to market accounts for about 19 percent of total O&M costs. Other O&M costs at the MRF account for about 3 percent of the total.

Labor at the composting facility comprises about 8 percent of total O&M costs, and other O&M costs at the composting facility comprise about 4 percent.

Administrative costs account for about 2 percent of total O&M costs, and educational and promotional expenditures account for about 3 percent.

3.3.2.3 Program Revenues or Credits. Two potential sources of credit were examined for offsetting the materials separation program costs. The first is revenue from the sale of recyclables. Currently, the Town of Islip pays a fee to a paper dealer for accepting separated newspapers. While the aluminum, ferrous metals, glass, and plastics are sold, their total revenue is less than the amount paid to the dealer for accepting the separated newspapers. While the Town of Islip expects that total revenues for marketing separated recyclables will be negative for 1990, no estimate is available for total expected revenue losses or losses on a per ton of commingled material basis.[10]

The second source of credit is the avoided landfill or MWC charge for materials separated. This credit is calculated by multiplying the weight of materials separated times the fee ($40/ton) that would have been charged if the separated materials had been landfilled or combusted in an MWC.[3] In 1990, it is expected that about 35,000 tons of recyclables and about 65,000 tons of yard waste will be diverted from the landfill or MWC through the materials separation programs.[3,9] Diverting 100,000 tons of materials from the landfill or MWC would result in a credit of $4 million. Table 3-14 presents a summary of credits included in this analysis.

Further credits might be assigned for the avoided or delayed cost of locating new landfill area or from the avoided or delayed cost of purchasing additional MWC capacity, but these credits were not considered in this analysis.

3.3.2.4 Net Program Cost. The net program cost is the difference between the annualized capital costs plus O&M costs and the materials sales revenues plus avoided landfill or MWC charges. All four items for 1990 are summarized in Table 3-15. Although, as noted in the previous sections,

TABLE 3-14. ISLIP MATERIALS SEPARATION PROGRAM CREDITS FOR 1990[a,b]

Item	Annual Cost Credit ($/yr)
Revenue from Sale of Recyclables	Negative[c]
Avoided Landfill Fee[d]	4,000,000
	=========
Total Credits	$4,000,000

[a] All credits are in 1990 dollars.

[b] References 3,4,9,10.

[c] Revenues are currently negative and are expected to be negative for the remainder of 1990. No value estimate was available.

[d] Landfill fee for 1990 is $40/ton. Total expected tonnage avoiding landfilling or combustion in an MWC is 100,000.

TABLE 3-15. ISLIP MATERIALS SEPARATION TOTAL PROGRAM COST SUMMARY FOR 1990

Weight of Total MSW Collected (tons)	400,000
Weight of Total Recyclables and Yard Waste Collected (tons)	100,000
Total Annualized Capital Costs ($)	1,900,502
Total O&M Cost ($)	8,336,000
Recyclable Materials Revenues ($)	0
Avoided Landfill or MWC Credit ($)	4,000,000

	Total $/yr	$/ton of Total Material Separated	$/ton of Total MSW Collected
Total Program Costs (without avoided landfill or MWC credit)	10,236,502	102	26
Net Program Costs (with avoided landfill or MWC credit)	6,236,502	62	16

these are partial costs since there was no quantitative information for a few of the cost components. The total estimated program cost without the credit for avoided landfill or MWC charges, which reflects the actual cost to the town for materials separation services, is approximately $10.2 million. The total program cost with the avoided landfill or MWC credit, which reflects the total net cost for the materials separation program, is approximately $6.2 million.

Table 3-15 presents these costs as $/ton of materials diverted from the landfill or MWC. The actual cost to the Town of Islip for each ton of material diverted is about $102. When the avoided landfill or MWC credits are included, however, the net cost is $62 for each ton of material diverted.

Costs are also presented in Table 3-15 in terms of $/ton of total MSW collected (trash plus recyclables and yard waste), which is a measure of the amount by which the materials separation program increases the cost of collecting and disposing of each ton of MSW. As shown in the table, when the avoided landfill or MWC credits are not included, the increased cost per ton of MSW collected is $26. When the avoided disposal credits are included, the net increased cost per ton of MSW collected is about $16.

The unavailable cost components -- capital and operating costs for municipal recyclables collection in 10 service districts and recyclable materials sales losses -- would increase the costs shown in Table 3-15. However, as stated in Section 3.3.2.3, potential credits from the avoided or delayed cost of purchasing additional MWC or landfill capacity is also not included in this analysis. Therefore, the actual effect of the unavailable cost and credit components on the program costs shown in Table 3-15 is unclear.

3.3.3 References for Section 3.3

1. Beyond 25 Percent: Materials Recovery Comes of Age. The Institute for Local Self-Reliance. April 1989. pp. 71-78.
2. Gallagher, Elizabeth. The Barge Can Stay Home. Biocycle. June 1989. pp. 42-44.
3. Information obtained from visit to the Town of Islip, NY. Lee Davis, Radian Corporation. November 8-9, 1989.

4. Records of recyclable materials separated and municipal solid waste landfilled by the Town of Islip, NY, in 1988 and 1989. Records submitted by Elizabeth Gallagher, Commissioner, Department of Environmental Control. Islip, NY. November 14, 1989.

5. Records of recyclable materials separated at the Islip, NY, materials recovery facility in 1988. Records submitted by Al Sanchez, Facilities Manager, Islip Resource Recovery Agency, Islip, NY. November 8, 1989.

6. Telecon between Joe Phillips, New York Department of Environmental Conservation, and Lee Davis, Radian Corporation. October 30, 1989.

7. Telecon between Elizabeth Gallagher, Town of Islip, NY, and Lee Davis, Radian Corporation. November 21, 1989.

8. Letter and cost estimates submitted by Elizabeth Gallagher, Department of Environmental Control, Islip, NY, to Lee Davis, Radian Corporation. January 2, 1990.

9. Telecon between Al Sanchez, Resource Recovery Agency, Islip, NY, and Lee Davis, Radian Corporation. January 16, 1990.

10. Telecon between Elizabeth Gallagher, Department of Environmental Control, Islip, NY, and Lee Davis, Radian Corporation. January 22, 1990.

3.4 RHODE ISLAND

3.4.1 Materials Separation Program Description

Concerns about potential adverse environmental impacts from landfilling have led the State of Rhode Island to reduce its dependence on landfilling through source reduction and recycling. The soils of Rhode Island are highly permeable, and most locations are not suitable sites for landfills. In 1986, the State of Rhode Island passed the Flow Control Law, which granted the Rhode Island Solid Waste Management Corporation (RISWMC) authority to control the flow of solid waste, mandated the construction of three resource recovery facilities, and mandated Statewide recycling, with a goal of recycling a minimum of 15 percent residential MSW.[1,2,3]

The RISWMC is a quasi-public agency which has the responsibility of managing the State's solid waste in Rhode Island, including siting, planning, and managing waste processing and disposal facilities.[1,3] The RISWMC receives no funding from the State of Rhode Island. It is funded primarily through landfill tipping fees.[1] The RISWMC is regulated by the Rhode Island Department of Environmental Management (DEM). The DEM is responsible for regulatory development and enforcement and provides some technical assistance to the RISWMC.[2]

Under the Flow Control Law, all municipalities in Rhode Island must institute curbside collection of recyclable materials from residences of less than six family units. All communities must implement these collection programs within 1 year of start-up of the State's MWC's which are still in planning stages. Each municipality receives planning guidance from the DEM, but must formulate its own plan. Then the municipality and the RISWMC negotiate the plan and sign a contract documenting the specifics of the agreement.

Municipalities receive full funding from the RISWMC for 3 years to implement and operate the curbside recyclables collection program. This funding includes the purchase of "blue bins" (i.e., 12.5 gallon rectangular plastic containers for holding commingled recyclables), collection trucks, reimbursement for collection labor and other operating and administrative expenses, and educational and promotional assistance. In addition, the municipalities deliver the collected materials free of charge to the MRF's owned and operated by the RISWMC. At the end of the first 3 years, each municipality will be responsible for financing its own collection program, but will still be able to use the MRF at no charge. Communities are required to achieve 15 percent separation of residential waste within 3 years of implementing their program.[1,2]

Currently, about one-half of the State's municipalities have fully instituted materials separation programs, and others are in late planning or early start-up stages. About two-thirds of the State's 333,000 households currently receive curbside collection services.[1]

Curbside materials separation programs in Rhode Island are all set up to collect partially commingled materials. Residents are required to place glass (including all clear, green, and brown container glass), tin cans, aluminum cans, and high density polyethylene (HDPE) and polyethylene terephthalate (PET) plastic beverage containers in the blue bin. Newspapers are bundled or placed in brown paper bags and stacked separately on top of the blue bin. At the curbside, the collector places the newspapers in one section of the collection truck and the remaining commingled materials in a separate section.[1,3,4]

Residents are asked to include only rinsed, unbroken container glass with caps removed; cookware, light bulbs, window glass, and other types of glass should not be included. Newspapers can include colored pages and inserts, but magazines and other papers are excluded at this time. The State is also planning to include separation and recovery of magazines.[5] Residents can tie newspapers together with string or place them in brown paper bags, but they are asked specifically not to use plastic bags. All tin cans can be included, and these should also be rinsed. In addition to cans, other types of aluminum, such as foil and pie plates, can be included as long as they have been cleaned. Currently, only plastic beverage containers (i.e., HDPE milk and water containers and PET soda bottles) are collected. The RISWMC is investigating the feasibility of including other rigid plastics, such as shampoo and detergent bottles, but it is often difficult to determine their resin composition, and cross contamination of plastic resins usually renders these materials less marketable.[1,3,4]

Rhode Island's first MRF, built in Johnston, Rhode Island, began operation in May 1989. The Johnston MRF separates commingled recyclables from all municipal collection programs in the State. The MRF, which is completely enclosed in a 40,000 square foot (sq. ft.) metal building, uses equipment manufactured by Bezner of West Germany. The MRF is operated by New England CRInc. under contract with the RISWMC.[1,3,4]

Recyclables collection trucks arriving at the MRF enter the building and deposit materials into two separate piles. Commingled glass, metal, and plastics collected in one compartment of the truck are dumped in a pile located near the feed hopper for the separation equipment. Newspapers collected in the other compartment of the truck are dumped in a pile located near a hopper which feeds a conveyor and bailer.[1,4]

Newspapers undergo some manual sorting. The newspapers are removed from brown paper bags or are untied and are tossed into the hopper. The brown paper bags are tossed into a separate pile to be bailed and sold whenever enough have accumulated. Other contaminants, such as plastic bags, magazines, or other contaminated or mixed papers are also removed, and these are discarded. The clean newspapers are conveyed from the hopper to a bailer which bails them for market.[1,4]

The commingled materials are fed through the separation process to separate the materials into their individual components. The materials are conveyed from the feed hopper to a manual sorting station where two to three workers pull aluminum pie pans and large nonrecyclable contaminants, such as propane tanks, cookware, and small appliances, from the conveyor. The aluminum pie pans are separated for recovery, and the nonrecyclables are discarded as residue. The remaining materials then pass under a rotating magnet which removes the ferrous metals. The nonferrous materials proceed to an inclined shaker where small broken glass is screened through 1.5 inch (in.) diameter holes. The large materials are conveyed to a density separator which separates the plastic bottles and aluminum cans from the glass bottles. The density separator separates the heavy and light materials by means of three rows, or "curtains," of weighted chains suspended over an inclined surface. The glass is heavy enough to fall through the chains, but the aluminum and plastic are not.[1,4]

The aluminum and plastic are conveyed over an eddy current magnet which imparts a repelling force on the aluminum cans ejecting them onto a separate conveyor. A handpicker inspects the aluminum can conveyor and removes any contaminants. These cans proceed through a can flattener and are then blown into a trailer for transport to market.[1,4]

The HDPE and PET plastics travel by a handpicking station where handpickers remove HDPE milk and water bottles and any contaminants. The HDPE is deposited into a separate bin, and the PET remains on the conveyor which feeds a PET bin. The HDPE is granulated and packed in large boxes for market. The PET bottles are perforated and bailed for market.

The glass fraction which had been separated by the density separator travels on a conveyor where handpickers remove colored glass and any remaining contaminants. The brown and green glass are deposited into separate bins. The clear glass continues on the conveyor and is deposited in a separate bin. Each color of glass is then crushed prior to being shipped to market.[1,4]

The steel cans separated by the magnet are shredded at the facility and are then shipped to a detinning mill.[1,4]

The Johnston MRF now processes about 80 tpd of commingled recyclables and about 100 to 110 tpd of newsprint. Usually the commingled materials are processed during an 8-hour day shift and newspapers are processed intermittently during the day or during a separate night shift. On average, about 22 workers are needed during the day shift.[1,4]

Table 3-16 shows the estimated annual tonnages of materials separated for recovery at the Johnston MRF and tons of total MSW landfilled for the area served by the Rhode Island separation program for 1990.[5,6,7] As shown in the table, about 40,000 tons of recyclables (about 6.9 percent of MSW generated) are recovered at the MRF each year and recycled. About 8,000 tons per year (about 1.5 percent of MSW generated) is attributed to nonrecyclable residue removed at the MRF. About 90 percent of this residue is attributed to glass broken during pick-up or while in transit. This residue is landfilled. About 534,000 tons (about 92 percent of total MSW generated) is landfilled. Of the 40,092 tons per year (tpy) recovered at the MRF, newspapers account for over 65 percent of the materials recovered, and glass accounts for about 18 percent. Tin cans, plastics, aluminum, and corrugated paper account for the remainder.

The operators at the MRF, New England CRInc., are responsible for marketing the recovered materials. New England CRInc. receives a materials processing fee from the RISWMC for each ton of material processed and also receives 10 percent of the revenue from the sale of materials. The RISWMC receives the remaining 90 percent of materials revenues.[1,6,7]

TABLE 3-16. TOTAL ESTIMATED ANNUAL TONNAGE OF MATERIALS SEPARATED AND MSW GENERATED IN RHODE ISLAND FOR 1990[a,b]

Material	Tons Collected	Percentage of Overall MSW Generated
Newspapers	27,636	4.7
Corrugated Paper	156	<0.1
Clear Glass	3,888	0.7
Brown Glass	1,452	0.2
Green Glass	1,896	0.3
HDPE Plastic	804	0.1
PET Plastic	924	0.2
Steel Cans	2,688	0.5
Aluminum	648	0.1
Total Materials Separated for Recovery	40,092	6.9
Total Materials Separated for Recovery	40,092	6.9
Total Residue from MRF	8,064	1.5
Total MSW Landfilled	534,000	91.7
Total MSW Generated	582,156	100.1[c]

[a] Materials recovery and residue values based on tonnages recorded at the Johnston MRF for December 1989 and January 1990. Total MSW landfilled based on yearly average estimate for area of State currently served by the separation program.

[b] References 5, 6, and 7.

[c] Greater than 100.0 percent due to rounding.

It should be noted that yard waste and materials separated by commercial businesses are not included in the calculation of the materials recovery rate. As discussed below, yard waste separation programs are still in the preliminary phase, and materials recovery values are not currently available from commercial businesses. Therefore, the recovery rates presented in Table 3-16 are partial estimates. However, representatives of the RISWMC believe that businesses and industries, along with help from waste haulers, are currently separating about 15 percent of the commercial waste stream.[5]

Currently, about two-thirds of the residents in Rhode Island are receiving curbside recyclables collection service. Reports from individual communities in Rhode Island which have materials separation programs in place show that about 15 percent of the residential portion of the waste stream is being separated for recovery.[2] As discussed above, about 6.9 percent of the total MSW is being separated in the areas served by the residential curbside separation program. This is similar to the rates achieved by residential curbside programs in both Seattle and Islip which achieve 5 to 6 percent separation through residential curbside recyclables pick-up. Residential curbside recyclables pick-up, however, is only one element of a comprehensive separation program. Recovery rates would rise with incorporation of yard waste separation and inclusion of tonnages from commercial waste separation.

The State of Rhode Island has adopted regulations for commercial waste recycling.[8,9] This program is administered jointly by the RISWMC and the DEM. According to the regulations, effective January 1, 1989, no commercial waste may be disposed of which contains more than 30 percent recyclable material by weight. After January 1, 1990, no commercial waste may be disposed of which contains more than 20 percent recyclable materials. Materials included in the calculation of the percentage of recyclables that must be separated include all of the materials in the residential curbside program plus corrugated cardboard, colored ledger paper, and white office paper.

A trained waste inspector visually inspects each load of commercial waste delivered to the landfill. If the waste inspector judges that the load has not been separated and contains too much recyclable material, the truck is directed to a sorting area. At the sorting area, the load is tipped, pictures are taken of the waste, and a sorting crew sorts and weighs the materials to determine compliance. If the load is not in compliance, the generator or transporter of the waste will be assessed a $500 fee for the weighing and sorting test. If a generator or transporter fails a weighing and sorting test, they must submit a materials recycling plan within 1 month or they will be prohibited from disposing at the landfill.[8,9]

In addition, after June 1990, all businesses with over 100 employees must submit a waste reduction/recycling plan. The plan must include a characterization of the business' waste and a plan to segregate recyclable materials. The RISWMC offers technical assistance by providing an RISWMC employee to go on-site to commercial businesses to help identify potential methods of waste reduction and materials for recycling.[8,9]

In addition, all businesses with over 100 employees must report to the DEM the type and amount of materials separated each year.[1,8] However, in Rhode Island, over 97 percent of all businesses are small businesses of less than 100 employees.[1] Representatives of the RISWMC stated that they will probably not be able to obtain good estimates of the total amount of commercial recycling given the predominance of small businesses and the difficulty in verifying reports submitted by the large businesses.[1]

The commercial businesses are generally expected to market their own materials; however, if the business has difficulty in locating markets, they may deliver the materials to the MRF for one-fourth of the $59/ton tipping fee charged at the landfill ($14.75/ton).[1,8]

Rhode Island regulations also include provisions for multi-family unit recycling.[1,8] Within 6 months of implementation of a community's curbside collection program, all apartment building owners in the community must submit materials separation plans to the DEM. The RISWMC provides recyclables containers, educational information, and recycling coordinator assistance to the building owners. The owners are required to cooperate with the DEM and RISWMC, to distribute information to the residents, to make materials separation available to the residents, and to negotiate contracts with haulers for recyclables collection. The haulers would be able to deliver the recyclables to the MRF at no charge as long as the municipality provides for trash disposal at the multi-family unit from which the recyclables are collected. Several thousand multi-family units which the recyclables are collected. Several thousand multi-family units are are currently served by recyclables collection programs.[5]

Rhode Island's materials separation programs do not currently include yard waste. Most yard waste is collected and disposed along with the trash. The RISWMC is conducting 3 different pilot yard waste collection and composting programs. Once these studies are completed, alternative recommendations will be made for yard waste management, and yard waste may be banned from landfills and MWC's.[1]

Rhode Island also has a source reduction program. Most activities thus far have been educational. The RISWMC provides posters and other educational materials to schools, businesses, and residences which stress the use of products which have one or more of the following characteristics: reusable, reliable, recycled, and recyclable. These educational materials offer suggestions such as leaving grass clippings on the lawn, and avoiding disposable products such as disposal razors and diapers.[1,10] Representatives from the RISWMC stated that it is not feasible to determine the amount of source reduction achieved with precision, and they have no plans to attempt to demonstrate a quantitative reduction.[1]

Future waste management plans for the State of Rhode Island include construction of a second MRF and 3 MWC's, each with a design capacity not to exceed 750 tpd. The second MRF will be built at Quonset Point, Rhode Island. The RISWMC has selected a builder, and construction on the MRF will begin soon. Two of the MWC's are still in permitting, and plans for the third MWC are still preliminary.[5]

3.4.2 Materials Separation Program Costs for Rhode Island

This section presents the capital costs, O&M costs, and economic credits for the State of Rhode Island's curbside materials separation program for 1990. Costs and credits are presented on a Statewide basis as reported by the RISWMC. As discussed in the previous section, the RISWMC bears the total cost of implementing and operating the community programs for the first 3 years.

3.4.2.1 Capital Costs. All capital equipment needed by communities to run their respective curbside materials separation programs was purchased by the RISWMC. The equipment purchased for the communities includes the recyclables containers (blue bins) and collection trucks.

Collection trucks are not purchased for all communities since some communities contract collection services. In such cases, these costs would be reflected in the collection costs. The RISWMC also pays the full capital cost of the MRF where the communities deliver the recyclables collected.

As shown in Table 3-17, the estimated annualized capital cost for the purchase of blue bins in 1990 is about $260,000, and the annualized capital cost for the purchase of collection vehicles is about $270,000. Bond interest for the Johnston MRF is about $230,000, and equipment depreciation is about $200,000 for 1990. Total estimated annualized capital costs for Rhode Island's community materials separation programs for 1990 are about $960,000.[2,6,7]

3.4.2.2 Operation and Maintenance Costs. Operation and maintenance costs for the Rhode Island materials separation program include processing fees to the contractor operating the MRF, fixed operating costs at the MRF, collection reimbursement costs paid to communities, and administrative costs including educational and promotional assistance to communities. These costs are summarized in Table 3-17. Total estimated O&M costs for 1990 are about $4.9 million.[2,6,7] These costs are all paid by the RISWMC.

The main O&M cost is for recyclables collection which comprises about 65 percent of the total O&M costs. Operating and maintenance costs for the MRF are the next largest cost, accounting for about 25 percent of total O&M costs.

3.4.2.3 Program Revenues or Credits. Two sources of credit are available for offsetting the materials separation program costs. The first is revenue from the sale of recyclables. As shown in Table 3-18, estimated revenues from sales of materials collected in Rhode Island in 1990 are about $1 million.[6,7]

The second source of credit is the avoided landfill charge for the materials separated. This credit is calculated by multiplying the weight of materials not landfilled due to materials separation times the fee ($13/ton) that would have been charged if the separated material had been landfilled. In 1990, it is estimated that 40,092 tons of materials will be diverted from the landfill.[2,6,7]

The total annual materials separation credit for these two sources, therefore, is estimated to be about $1.5 million for 1990. Further credits

TABLE 3-17. ESTIMATED CAPITAL AND OPERATION AND MAINTENANCE COSTS FOR RHODE ISLAND'S MATERIALS SEPARATION PROGRAM FOR 1990[a,b]

Annualized Capital Costs	$/year
Bond Interest on MRF	228,480
Equipment Depreciation for MRF	201,600
Collection Containers	260,720
Collection Vehicles	273,214
Total Annualized Capital Cost:	964,014
Annual Operation and Maintenance Costs	
MRF O&M Costs	
O&M Fee to Contractor	1,067,712
Residue Disposal	47,112
Electricity	70,116
Water	5,076
Lawn Service	29,760
Materials Shipping	92,538
Total Annualized MRF O&M Cost:	1,312,314
Collection Costs	
Cost reimbursements to communities	121,920
Other Administrative Costs	
Administrative, educational, and promotional assistance	460,000
Total Annual O&M Cost:	4,894,234
Total Annualized Capital and O&M Cost:	5,858,248

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[a] References 2, 6, and 7.

[b] All costs are in 1990 dollars.

TABLE 3-18. ESTIMATED CREDITS FOR RHODE ISLAND'S MATERIALS SEPARATION PROGRAM FOR 1990[a,b]

Item	Annual Credit ($/yr)
Revenue from Sale of Recyclables	1,022,268
Avoided Landfill Fee[c]	521,196
Total Credits	1,543,464

[a] References 2, 6, and 7.

[b] All credits are in 1990 dollars.

[c] Landfill fee is $59/ton for commercial waste and $13/ton for community residential waste. The $13/ton rate is used in calculating avoided landfill fee credits since the materials separated would have been landfilled at this rate. Total tonnage avoiding landfilling is estimated to be 40,092.

TABLE 3-19. ESTIMATED TOTAL PROGRAM COST SUMMARY FOR RHODE ISLAND FOR 1990[a]

Weight of Total MSW Collected (tons) = 582,156

Weight of Materials Separated (tons) = 40,092

Total Annualized Capital Costs ($) = 964,014

Total O&M Costs ($) = 4,894,234

Materials Sales Revenue ($) = 1,022,268

Avoided Landfill Fee ($) = 521,196

	($/yr)	$/ton of Total Materials Separated	$/ton of Total Materials Collected
Total Program Costs (without avoided landfill credit)	4,835,980	121	8.30
Net Program Costs (with avoided landfill credit)	4,314,784	108	7.41

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[a] References 2, 6, and 7.

might be assigned for the avoided or delayed cost of buying new landfill area or MWC capacity, but these credits were not considered in this study. It should be noted that the $13/ton included in the credit calculations is a relatively low value for a landfill tipping fee. Tipping fees for landfills and MWC's are often much higher.

3.4.2.4 Net Program Cost. The net program cost is the difference between the annualized capital cost plus total O&M cost and the sales revenues plus avoided landfill charges. All four items estimated for 1990 are summarized in Table 3-19. The total estimated program cost without the credit for avoided landfill fee charges, which reflects the actual cost to the RISWMC for materials separation services, is approximately $4.3 million for 1990.

Table 3-19 presents these costs as $/ton of recyclable materials diverted from the landfill. The actual cost to the RISWMC for each ton of recyclable materials diverted from the landfill is $121. When the avoided landfill credit is included, the net cost is reduced to $108/ton of recyclable materials diverted from the landfill.

Costs are also presented in Table 3-19 in terms of total MSW collected (trash plus recyclables), which is a measure of the amount by which the materials separation program increases the cost of collecting and disposing of each ton of MSW. As shown in the table, when the avoided landfill credit is not included, the increased cost per ton of MSW collected is about $8.30. When the avoided landfill credit is included the net cost per ton of MSW collected in about $7.41.

3.4.3 References for Section 3.4

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2. Recycling - Program Design and Planning. Informational packet compiled by the Rhode Island Solid Waste Management Corporation.

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5. Teleconference between Lee Davis, Radian Corporation, and Dante Ionata, Rhode Island Solid Waste Management Corporation. October 15, 1990.

6. Monthly Economic and Performance Summary - Johnston Materials Recycling Facility. Compiled by the Rhode Island Solid Waste Management Corporation. December 1989.

7. Monthly Economic and Performance Summary - Johnston Materials Recycling Facility. Compiled by the Rhode Island Solid Waste Management Corporation. January 1990.

8. Regulations for Reduction and Recycling of Commercial and Non-Municipal Residential Solid Waste. Compiled by the Rhode Island Solid Waste Management Corporation. June 28, 1988.

9. Commercial Solid Waste Recycling and Reduction Program-Enforcement Plan. Guidelines for Recycling Technical Assistance and Delivery of Segregated Waste to State-Owned Disposal Facilities. Compiled by the Rhode Island Solid Waste Management Corporation. January 1, 1989.

10. Rhode Island Source Reduction Task Force Report. Compiled by the Rhode Island Solid Waste Management Corporation. November 1987.

4.0 CASE STUDIES OF CENTRALIZED FACILITIES SEPARATING UNSORTED MSW

This section presents case studies of two centralized materials separation facilities which use a combination of mechanical and manual techniques to separate recoverable materials from unsorted MSW. Each case study contains information on how separation is achieved at each facility, the amounts and fate of each material separated, and the capital and annualized costs of the facility. One facility is located in Crestwood, Illinois, and the other in Eden Prairie, Minnesota. Both facilities operate at transfer stations. However, the technologies employed at either facility could also be employed at MWC's or at landfills. Descriptions of the two facilities are presented below.

4.1 XL DISPOSAL CORPORATION, CRESTWOOD, ILLINOIS[1]

4.1.1 Facility Description and Materials Separation Operations

4.1.1.1 General Plant Operations. The XL Disposal Corporation operates a materials separation facility at a transfer station which accepts waste from the Crestwood, Illinois, area near Chicago. Residential and commercial waste are delivered to the facility by local curbside haulers. All trucks are weighed as they enter the facility. All of the residential waste and some of the commercial waste undergo processing to separate some materials for recovery. Construction/demolition wastes and some commercial wastes which do not contain a high proportion of recyclables are not processed. Residual and nonrecoverable wastes are loaded into larger trucks for transport to one of several landfills which are located 50 to 90 miles away.

4.1.1.2 Materials Separation Operations. The separation facility is housed in one building which has three sections separated by concrete walls. The three sections are: (1) tipping floor for waste which is to undergo processing; (2) materials separation section; and (3) section where compostable wastes and nonrecoverable wastes from the separation process are deposited and loaded onto trucks for transport to the composting facility and the landfill, respectively. This third section also serves as the tipping floor for waste which does not undergo processing.

Figure 4-1 provides a schematic diagram of the materials separation process. Unsorted municipal waste entering the facility is dumped onto the concrete tipping floor in the first section of the building. Waste designated for processing is pushed by a front-end loader into a pit which feeds a conveyor system. Large items, such as appliances or large automobile parts, are pushed aside and do not enter the materials separation system.

The waste feed conveyor exits the tipping area through an opening in the wall and conveys the waste into the second section of the facility where automated materials recovery and handpicking are performed. Next to the conveyor is a handpicking station where cardboard and/or newspaper is periodically recovered. Current practice is to man the station for only 2 to 3 hours per day to separate cardboard from the commercial waste. According to Mr. Ed Pruim, President of XL Disposal Corporation, the cardboard content of residential waste is too low to justify handpickers. However, at certain times of the day, commercial waste is delivered which has a high proportion of cardboard. Mr. Pruim added that if the market for newspaper improved, he would consider separating newspapers, but presently there is no demand.

After passing by the initial handpicking station, the conveyor dumps the waste into the automated materials separation system manufactured by National Recovery Technologies, Incorporated (NRT). The first component of the NRT system is a large inclined, rotating drum (see Figure 4-1). The drum measures 12 ft in diameter and 35 ft in length and has a capacity of about 400 tpd of MSW. Large knife blades around the interior circumference of the drum slash open paper and plastic trash bags, and the rotating action of the drum homogenizes the waste. The tumbling action also breaks glass objects into small pieces. Permanent magnets mounted on the interior circumference of the drum near the exit trap ferrous objects which are then scraped off and deposited onto a separate ferrous metals conveyor. Lifters at the drum's exit separate the remaining material by size and density.

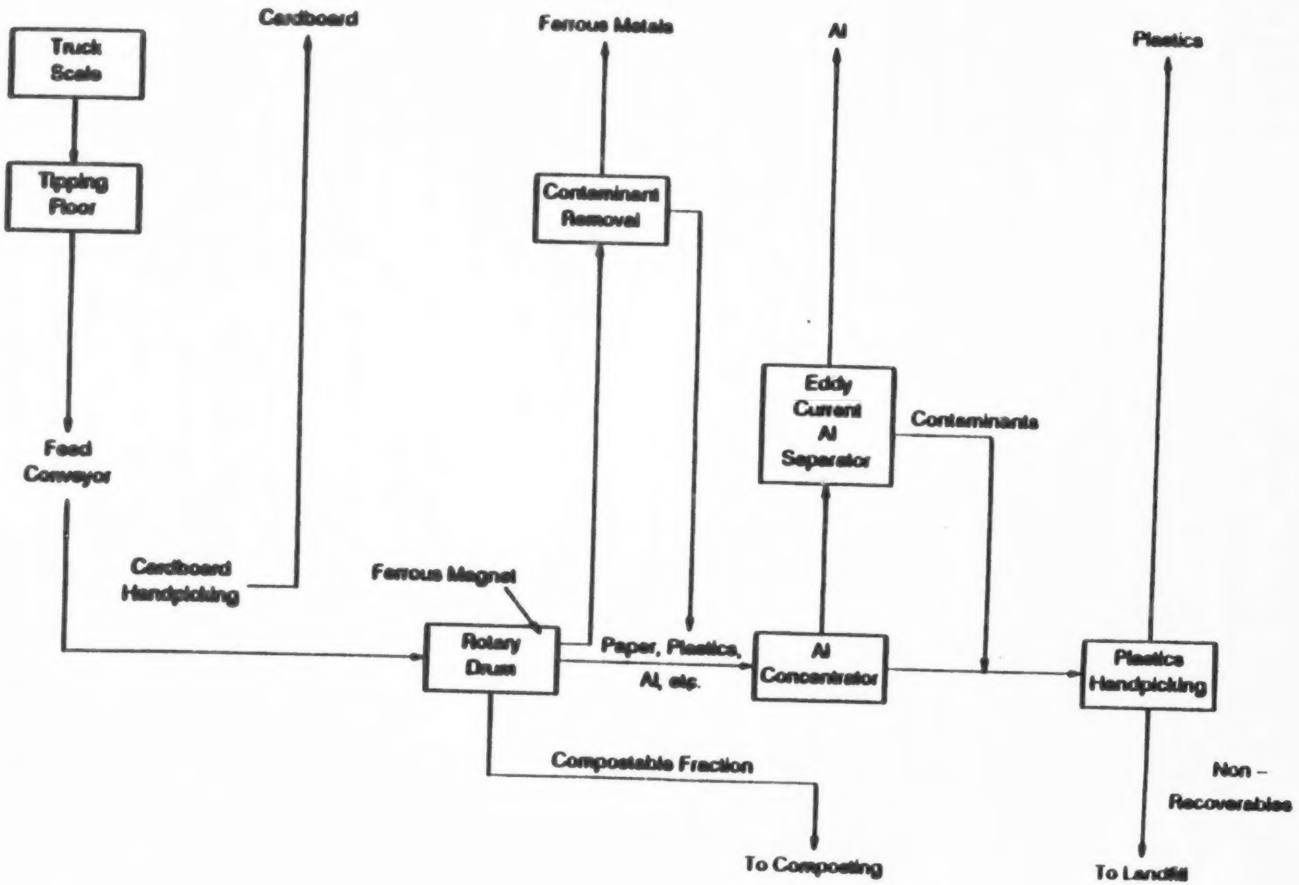
Truck Scale
Tipping Floor
Feed Conveyor
Cardboard Handpicking
Cardboard
Ferrous Magnet
Rotary Drum
Ferrous Metals
Contaminant Removal
Paper, Plastics, Al, etc.
Compostable Fraction
To Composting
Al
Eddy Current Al Separator
Al Concentrator
Contaminants
Plastics
Plastics Handpicking
Non - Recoverables
To Landfill

Figure 4-1. Schematic Diagram of Materials Separation Process at XL Disposal Corporation

Small dense materials such as broken glass, grit, and grass clippings are deposited on a separate conveyor, and the remaining materials, primarily aluminum cans, paper, and plastics, exit the bottom of the drum.

The magnetically removed ferrous portion of the waste travels on a conveyor to the ferrous recovery bin. Because the ferrous fraction still contains some contaminants such as pieces of paper or plastics, there is a flexible plastic curtain at the discharge of the conveyor which deflects the nonmetallic contaminants into a bin. The ferrous metals are retained on the conveyor by a magnetic head pulley. This rotating magnet holds the ferrous metals on the conveyor, allowing them to pass through the flexible curtain and under the head pulley. After passing under the head pulley, the ferrous metals are scraped off and deposited into a separate bin.

The small dense fraction consisting mostly of yard waste, glass, and grit travels from the rotating drum on a separate conveyor. At one location, air jets blow air across the conveyor to remove light contaminants such as small paper and plastic film. The remaining small dense material travels through an opening in the wall to the third section of the building where it is deposited in a separate pile. This material is later removed from the building and taken to a separate composting pile located outside of the facility.

The largest volume fraction of the waste stream, consisting primarily of aluminum cans, paper, and plastic containers, exits the drum on a separate conveyor and passes through the aluminum concentrator. In the aluminum concentrator, the waste is electronically scanned for the presence of nonferrous metals. When nonferrous metals are detected, sensors activate one or more air valves that provide a pulse of air propelling the objects out of the waste stream and onto a separate slide. There are 15 sets of sensors/air valves in the aluminum concentrator, one row of 7 and one row of 8 in an offset position. The air pulse in the aluminum concentrator also ejects some paper and plastic along with the aluminum. As the aluminum concentrate approaches the bottom of the slide, it passes over an eddy current magnet which imparts a repelling force on the aluminum items. The aluminum is ejected over a barrier onto a separate conveyor while the non-aluminum items fall onto a conveyor which rejoins the remaining large fraction. The aluminum is transported to a separate bin where a handpicker removes aluminum items such as pie pans since aluminum cans have a higher sale value if they are separated from other aluminum materials.

The remaining fraction, which consists mostly of paper and plastic, passes by a handpicking station where three or four workers remove plastic containers and any remaining aluminum items from the moving waste conveyor. Three plastic fractions are collected: (1) PET beverage bottles, (2) colored HDPE containers, and (3) clear HDPE milk containers. These items are pulled from the waste by hand and dropped into chutes which lead to separate bins. The residual nonrecovered waste, which is primarily paper, then travels through an opening in the wall of the materials separation area and is deposited on the floor of the reloading and exit section of the facility. This residual waste is then loaded by front-end loader onto trucks for transport to a landfill.

The materials separation system presently operates 8 to 10 hours per day and processes about 20 tons of MSW per hour. There are 7 to 10 employees, including a plant operator, an assistant plant operator, and handpickers. Other maintenance personnel, such as electricians, do not work full time, but work on an as-needed basis. In the near future, a second shift will be added, and the plant will operate 20 hours per day and process about 400 tpd of MSW.

The separation system does not discharge emissions to the atmosphere. It is a closed loop system which recycles all process air. Thus, no APCD is needed.

4.1.1.3 Fate of Recovered Materials. The ferrous material, which consists mostly of tin cans, is sold to a local scrap dealer. The scrap dealer shreds the material, removes some contaminants such as paper, and mixes it with other scrap. This mixed scrap is then sold to steel mills for the manufacture of new steel. For steel production, steel producers normally prefer to use mixed scrap that contains no more than 5 percent ferrous metal derived from MSW.

Aluminum scrap, especially cans, is in high demand, is economically valuable, and is sold directly to aluminum producers.

The recovered PET plastic is sold to a company which uses it to make products such as polyester fiber insulation used in jackets and sleeping bags. The HDPE plastics, both colored and clear, are sold to a company which uses them to make products such as drain pipe and plastic lumber.

Separated cardboard is bailed and sold to a papermill for the manufacture of new boxboard materials. Paper and newspaper are currently being landfilled. Mr. Pruim said that there is a paper company located about 2 miles from the facility. He is currently looking into the possibility of separating and shipping some newspaper to the papermill, but there was not presently a strong enough market for separated newspaper.

The compostable fraction, including yard waste, grit, glass, and other small dense materials, is to be taken to an off-site composting facility. Mr. Pruim said that the compostable fraction will be mixed with 20 percent wood chips which have been soaked in compost bacteria. The material will be composted outdoors for about 60 days. The broken glass aids the composting action by providing air spaces throughout the material. Once the material has been composted, Mr. Pruim intends to use it as final landfill cover. He said that he believes it should also be of high enough quality to use for other purposes such as landscaping or agriculture. However, the glass and other contaminants would have to be screened out first. Currently, the composting process is not in full operation. The compostable fraction is being placed in a pile outside of the facility pending start-up of the composting operation.

Within the next year, a wood chipper will be purchased to chip lumber (abundant in construction waste), wooden pallets, and tree limbs. The chipped wood could then be composted or used as mulch.

4.1.1.4 Materials Separation System Performance. Table 4-1 shows that XL Disposal Corporation's separation operations separate about 20 percent of the total weight of MSW processed. Of the 20 percent separated, the majority (11.4 percent) consists of the compostable fraction. The second largest fraction is corrugated paper (4.1 percent), followed by ferrous metals (3.3 percent), aluminum (0.74 percent), and plastic (0.48 percent).[2]

The majority of the separation equipment, including the rotating drum, magnets, air classifiers, aluminum separators, and associated computer controls were purchased from NRT. Conveyors and other equipment were purchased from other vendors. Dr. Charles Roos, President of NRT, said that the purchase agreement with XL Disposal Corporation guaranteed at least 70 percent automated separation of aluminum and 85 percent automated

TABLE 4-1. TONNAGE OF MATERIALS SEPARATED AT THE XL DISPOSAL CORPORATION FACILITY[a]

	Tons Per Week	Percent of Total
Total MSW Processed	1,534	100
Tons Separated		
Aluminum	11.3	0.74
Ferrous Metals	50.3	3.3
Plastic	7.3	0.48
Corrugated Paper	63.1	4.1
Compost[b]	175.1	11.4
Total Materials Separated	307.1	20.0

[a] Reference 2.

[b] The "compost" fraction is composed of a mixture of yard waste, food waste, broken glass, grit, and other small dense organic and inorganic materials.

separation both of glass and ferrous metals. Mr. Pruim said that while he has not yet tested removal efficiencies of individual components, he is satisfied that he is getting a greater separation efficiency than that guaranteed by NRT. He said that he believes that he is getting about 90 percent automated separation of aluminum. Separation efficiencies of compostable materials and manually separated materials have also not been determined.

The materials separation facility and associated equipment supplied by NRT are designed for a daily throughput of 400 tpd of MSW based on 20 hours per day of operation. At present, the facility is only operating at about half this capacity, 8 to 10 hours per day. Mr. Pruim said that they plan to experiment with the system and determine separation efficiencies at capacity as well as above capacity to determine the operating rate at which the separation efficiency drops. If the system performs well above the design capacity, they may choose to operate at a higher waste throughput.

4.1.1.5 Handpicking Operations. The initial handpicking station, used for removing cardboard and possibly newspaper in the future, is located on an open, elevated metal platform. The handpicking station for plastics and residual aluminum is located in a glass-enclosed room which is climate controlled and supplied with fresh air. The workers pick the plastic and aluminum from a single conveyor which is about 3 ft in width. Waste on the conveyor is about 8 to 12 inches deep. Workers generally wear cotton gloves. Mr. Pruim said that some workers had tried rubber gloves, but found them too uncomfortable since moisture and heat build up in the gloves over the course of a shift. They also have the option of wearing a plastic apron and a particle mask; however, the workers do not always choose to wear them. The handpicking station is relatively clean, and there is no objectionable smell.

4.1.2 Materials Separation Costs and Credits for the XL Disposal Corporation

This section presents the capital costs, O&M costs, and economic credits of the materials recycling facility operated by the XL Disposal Corporation. Estimated costs are also given for the construction and operation of a new materials separation facility with the same capacity. All costs and credits are presented in 1990 dollars.

4.1.2.1 Capital Costs.[2] Capital costs include the transfer station modifications, the automatic materials separation equipment, scales, and miscellaneous equipment such as a front-end loader, bailers, and material bins. Because XL Disposal Corporation's existing facility was used for the materials recycling center, their costs were less than the costs of a new facility. Table 4-2 presents both XL Disposal Corporation's actual capital costs and XL Disposal Corporation's estimate of capital costs for a new facility. New facility costs at $5.5 million are close to twice the costs actually incurred by XL Disposal Corporation. Most of the extra cost for a new facility would be for the property and construction costs of a new transfer station, as discussed below.

Capital costs were annualized using an interest rate of 10 percent and assuming an equipment life for each item as listed in Table 4-2. As shown in the table, annualized capital costs are about $350,000 for XL Disposal Corporation as compared to about $620,000 for a new facility.

The major capital cost for XL Disposal Corporation is for modifications to the transfer station, which is a concrete structure that houses the materials separation plant. For XL Disposal Corporation, expansion costs for their existing transfer station were about $1.5 million or 50 percent of their total capital costs. For the construction of a new facility, the property and the transfer station building would cost approximately $4 million or 73 percent of the total capital cost. The automatic materials separation equipment described in Section 4.1.1.2 is the next largest capital cost item at $1.1 million.

4.1.2.2 Operation and Maintenance Costs.[2] Operation and maintenance costs are presented in Table 4-3 and include operating and administrative labor, maintenance materials, property taxes, insurance, and utilities. As shown in Table 4-3, total O&M costs for XL Disposal Corporation are $617,000 per year and are assumed to be the same for both XL Disposal Corporation and a new facility. Operating and administrative labor is the major O&M cost, accounting for 80 percent of total O&M costs.

4.1.2.3 Program Revenues and Credits. Three sources of revenue or credit are assigned for the materials separation program. The first is revenue from the sale of recyclables. For this study, aluminum was assigned a recycling value of $900/ton, ferrous metals were assigned $40/ton, cardboard was assigned $30/ton, and plastics were assigned

TABLE 4-2. CAPITAL COSTS FOR A MATERIALS SEPARATION FACILITY[a,b]

	XL Disposal Corporation Capital Cost ($)	New Facility Capital Cost ($)	Life (yrs)	XL Disposal Corporation Annualized Capital Cost ($)	New Facility Annualized Capital Cost ($)
Transfer Station	1,450,000	4,025,000	30	153,815	426,969
Separation Equipment	1,100,000	1,100,000	15	144,621	144,621
Scales	50,000	50,000	15	6,574	6,574
Other[c]	325,000	325,000	15	42,729	42,729
Total	2,925,000	5,500,000		347,739	620,893

[a] Reference 2.

[b] All costs are 1990 dollars.

[c] Includes front-end loader, bailers, material bins, and other unspecified equipment.

TABLE 4-3. ANNUAL OPERATION AND MAINTENANCE COSTS FOR A MATERIALS SEPARATION FACILITY[a,b,c]

Property Taxes		$ 15,000
Insurance		60,000
Utilities		36,000
Materials		12,000
Labor		416,000
Administration		78,000
	Total	$ 617,000

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[a] Reference 2.

[b] These are the O&M costs reported by XL Disposal Corporation and are assumed to be the same for a new facility.

[c] All costs are in 1990 dollars.

$140/ton.[3] No revenue was assigned for compost because XL Disposal Corporation does not currently market their compost. As shown in Table 4-4, XL Disposal Corporation will receive an estimated revenue of about $780,000 from the sale of recyclables in 1990.

The second source of credit is the landfill fee which is avoided by recycling. This credit is calculated by multiplying the weight of the materials recycled (tons) times the landfill fee ($/ton). The estimated credit for the avoided landfill fee for XL Disposal Corporation in 1990 is estimated to be approximately $350,000 based on a landfill fee of $22/ton.[3]

The third source of credit is the avoided transportation cost of hauling the separated materials from the transfer station to the landfill. Average round trip hauling costs for XL Disposal Corporation are about $7.50/ton. Therefore, for each ton of material that is separated, $7.50 is saved in avoided hauling cost. Avoided transportation costs for 1990 are estimated to be about $120,000.[3]

The total materials separation credit from these three sources is estimated to be about $1.25 million. Both XL Corporation and a new facility were assumed to receive this credit. Further credit might be assigned for the avoided or delayed cost of buying new landfill area, but this credit was not considered in this study.

4.1.2.4 Total Program Costs/Credits. The total program costs and credits include annualized capital costs, O&M costs, materials sales revenues, avoided landfill fees, and avoided transportation costs. These items are summarized in Table 4-5. The total program cost without the avoided landfill credit and the avoided long-haul transportation credit (which is the actual cost to operate the facility) is $181,000 for XL Disposal Corporation and $454,000 for a new facility. With avoided landfill fees and avoided transportation credits, the total program costs become negative, which reflects a net savings. This savings, which reflects the net benefit of materials separation compared to landfilling, is about $290,000 for XL Disposal Corporation and $17,000 for a new facility.

Table 4-5 presents these costs as $/ton of recyclable materials diverted from the landfill. The actual cost for each ton of recyclable materials diverted from the landfill is about $11.50 for XL Disposal

TABLE 4-4. XL DISPOSAL CORPORATION'S MATERIALS SEPARATION CREDITS FOR 1990[a,b]

Item		Annual Credit ($/yr)
Revenue from Sale of Recyclables:		
	Tons Separated[c]	
Aluminum	586	527,400
Ferrous Metals	2,616	104,604
Plastic	380	53,200
Corrugated Paper	3,281	98,430
Compost	9,103	0
Subtotal	15,966	$ 783,670
Avoided Landfill Fee[d]		351,252
Avoided Long-Haul Transportation Cost[e]		119,745
Total Credits		$1,254,667

[a] References 1, 2, and 3.

[b] All credits are 1990 dollars.

[c] Annual tons separated are based on weekly tons presented in Table 4-1 times 52 weeks.

[d] Avoided Landfill Fee = 15,966 tons separated * landfill fee ($22/ton).

[e] Avoided Long-Haul Cost = 15,966 tons separated * round trip transportation cost to landfill ($7.50/ton).

Corporation and $28.50 for a new facility. When the avoided landfill fees and avoided transportation costs are included, the net savings is about $18.20/ton for XL Disposal Corporation and $1.10/ton for a new facility.

Total program costs are also presented as $/ton of total MSW collected (including trash and recyclables), which is a measure of the amount by which the materials separation program raises or lowers the cost of disposing of each ton of MSW. As shown in Table 4-5, when avoided landfill fees and avoided transportation costs are not included, the increased cost per ton of MSW collected is $2.30 for XL Disposal Corporation and $5.70 for a new facility. When avoided landfill fees and avoided transportation costs are included, the decreased cost per ton of MSW collected is about $3.60 for XL Disposal Corporation and $0.21 for a new facility.

4.1.3 References for Section 4.1

1. Davis, L., Radian Corporation. Trip Report -- Site Visit: XL Disposal Corporation Materials Separation Facility. September 25, 1989.

2. Letter from Edward H. Pruim, President, XL Disposal Corporation to Jack R. Farmer, Director, Emission Standards Division, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency. February 5, 1990.

3. Telecon between Mr. Bob Pruim, XL Disposal Corporation, and Lee Davis, Radian Corporation. March 15, 1990.

TABLE 4-5. MATERIALS SEPARATION TOTAL PROGRAM COSTS[a,b]

	XL Disposal Corporation	New Facility
Weight of Total MSW Collected (tons)	79,768	79,742
Weight of Total Materials Separated (tons)	15,966	15,966
Total Annualized Capital Costs ($)	347,739	620,893
Total O&M Costs ($)	617,000	617,000
Recycling Revenues ($)	783,670	783,670
Avoided Landfill Fee ($)	351,252	351,252
Avoided Long-Haul Cost ($)	119,745	119,745

	XL Disposal Corporation			New Facility		
	Costs ($/yr)	($/ton of Recyclable Material Diverted From the Landfill)	($/ton of Total MSW Collected)	Costs ($/yr)	($/ton of Recyclable Material Diverted From the Landfill)	($/ton of Total MSW Collected)
Total Program Costs (without Avoided Landfill and Long-Haul Credits)	181,069	11.53	2.27	454,223	28.45	5.70
Total Program Costs (with Avoided Landfill and Long-Haul Credits)	-289,928[c]	-18.16	-3.63	- 16,774	- 1.05	-0.21

[a] References 1, 2, and 3.

[b] All costs and credits are in 1990 dollars.

[c] Negative values indicate a net credit or savings.

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4.2 REUTER RECYCLING, INC., EDEN PRAIRIE, MINNESOTA[1]

4.2.1 Facility Description and Materials Separation Operations

4.2.1.1 General Facility Description. The Reuter Recycling, Inc., facility is located in Eden Prairie, Minnesota, just outside of Minneapolis. The facility, including offices, tipping floor, and processing area, is completely enclosed in a 70,000 sq. ft. building constructed of concrete. The facility accepts about 450 to 470 tons of MSW per day. The facility operates at full permitted capacity (2 processing lines) for 1 shift during the day, and at half capacity (1 processing line) for 1 shift at night. As-received waste is comprised of about 75 percent residential waste and 25 percent commercial waste. About 40 to 50 percent of this MSW (mainly paper) is processed into refuse-derived fuel (RDF), 25 to 30 percent is composted, 12 to 15 percent is recovered for materials recycling, and about 10 to 15 percent is sent to a landfill. The majority of the separation equipment and RDF processing equipment was purchased from Buhler-Miag, a Swiss company. The facility has been in operation since 1987.

4.2.1.2 Materials Separation Operations. Figure 4-2 provides a schematic diagram of the materials separation process. Trucks are weighed on scales as they enter the facility and as they exit the facility. Trucks deliver unsorted waste to the tipping floor section of the building which is completely enclosed. A front-end loader is used to push the waste into a large pile in one corner of the building. The front-end loader operator also takes waste from the pile and deposits it onto an open area of the floor where two to three handpickers remove corrugated paper, automobile batteries, tires, lumber, large tree limbs, and other large items such as appliances or large automobile parts. These items are placed in separate piles for later recovery or transport to a landfill. After the waste has been presorted on the tipping floor, the front-end loader operator pushes the remaining waste into a hopper which feeds either of two parallel conveyors. The conveyors exit the tipping floor area through openings in the wall and travel into the separate section of the building where automated materials recovery, handpicking, and fuel processing is performed.

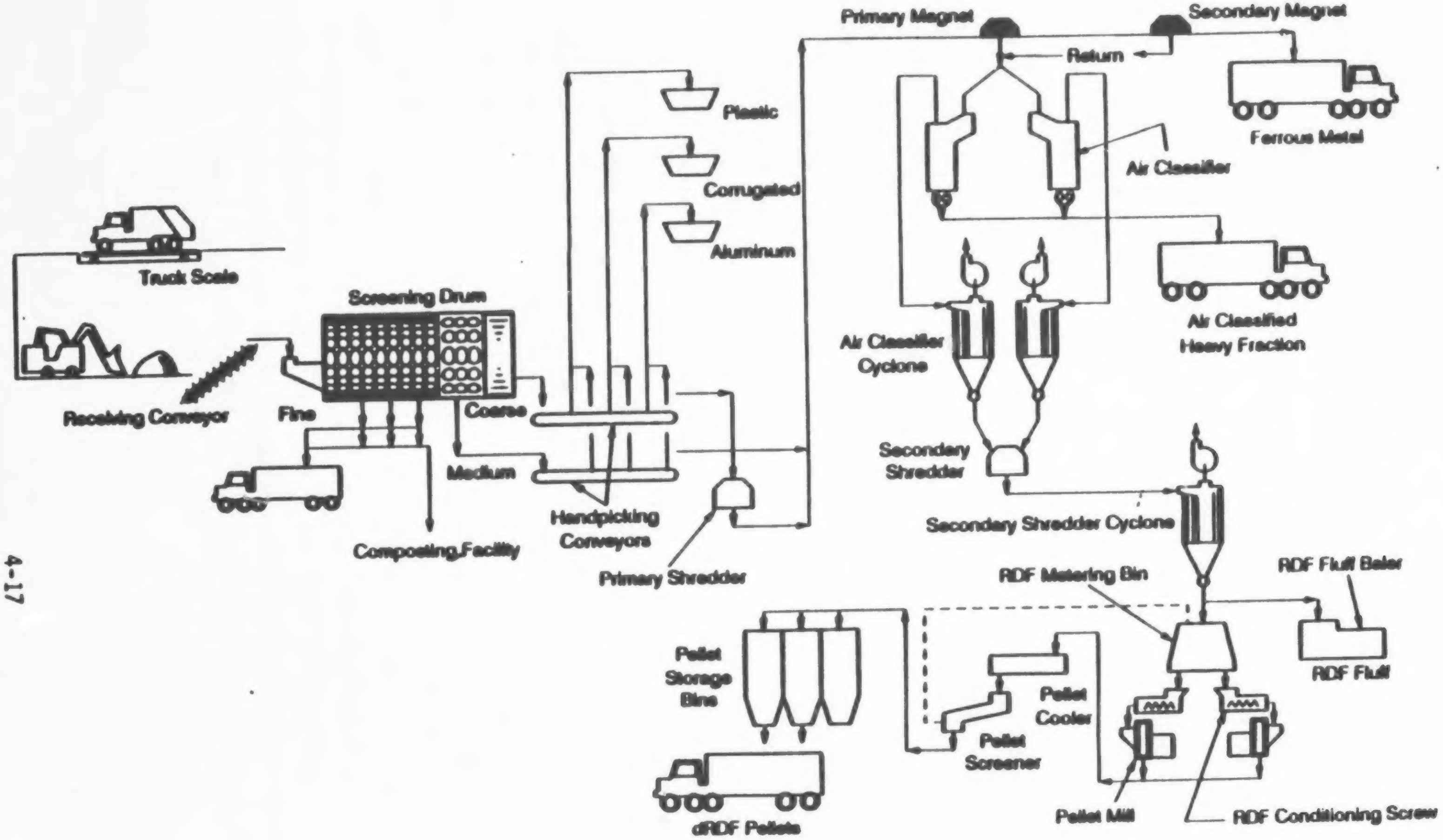
Primary Magnet
Secondary Magnet
Return
Ferrous Metal
Plastic
Corrugated
Aluminum
Air Classifier
Truck Scale
Screening Drum
Air Classifier Cyclone
Air Classified Heavy Fraction
Receiving Conveyor
Fine
Coarse
Medium
Secondary Shredder
Handpicking Conveyors
Secondary Shredder Cyclone
Composting Facility
Primary Shredder
RDF Metering Bin
RDF Fluff Baler
Pellet Storage Bins
Pellet Cooler
RDF Fluff
Pellet Screener
Pellet Mill
RDF Conditioning Screw
dRDF Pellets

Figure 4-2. Schematic diagram of materials separation and RDF production processes at Reuter Resource Recovery facility.

The conveyors feed two parallel processing lines where waste is first fed into a rotating drum sieve. The drum sieve separates waste into three size fractions: (1) fine waste which is screened through 1 3/8 in. diameter holes, (2) medium waste which is screened through 8 in. diameter holes, and (3) large waste which passes through the drum sieve. The fine fraction travels by conveyor to a truck for transportation to an offsite composting area.

The medium and large fractions proceed on to separate conveyors and past the handpicking station. At the handpicking station, workers manually remove aluminum, HDPE plastic containers, low density polyethylene (LDPE) plastic film, PET plastic beverage bottles (clear and green containers are separated), residual corrugated paper, and textiles. Handpicking is performed to separate materials for recovery and to keep contaminants from entering the RDF production process.

After exiting the handpicking station, the large waste fraction enters a primary hammermill shredder which shreds the waste to about 6 inches in diameter. According to Mr. Jim Markeson of Reuter Recycling, Inc., there is some risk of explosion from shredding propane tanks or gas tanks that may be overlooked, but no serious explosions have occurred due to effective handsorting of these materials on the tipping floor as well as on the handsorting conveyor. The shredder is designed to vent to the exterior of the building in the event of an explosion.

The reduced fraction exiting the shredder then joins the medium fraction from the rotating drum sieve and the combined materials proceed through a primary magnet which removes ferrous metals. The ferrous metal fraction removed by the primary magnet then travels through a secondary magnet to further separate the ferrous metals from any contaminants (paper) which may have been entrapped in the ferrous metals during separation at the primary magnet. The ferrous metals are taken by conveyor to a truck for shipment to a ferrous metals scrap dealer. At this point, materials separation is essentially complete. The remaining waste consists of paper and any contaminants that may have passed through the separation processes. This remaining waste then proceeds to the RDF production segment of the plant.

4.2.1.3 Refuse-Derived Fuel Production Operations. The RDF production process is also shown in the schematic diagram in Figure 4-2. After passing through the materials separation processes, the paper fraction passes through an air classifier and an air classifier cyclone to separate any heavy contaminants. The heavy contaminants are collected for shipment to a landfill or for composting. The remaining paper then enters a secondary hammermill shredder where it is reduced to a size of about 4 in. in diameter. The remaining paper (fluff RDF) is then either bailed or densified into RDF pellets.

To make densified RDF pellets, the fluff is first densified into a flake with a conditioning screw and then pressed into densified pellets in a pellet mill. The resulting cylindrical pellets, which measure about 3/4 in. in diameter by 2 in. in length, are then cooled and transported to storage bins where they are stored until being transported to an energy-generating facility. These densified RDF pellets have an energy value of about 8,000 Btu/lb and an ash content of 6 to 9 percent.

4.2.1.4 Proportional Distribution of Separated Materials. According to Reuter, Inc., the operations at the facility process the total MSW waste stream into the following components (by weight percent): bailed fluff RDF and densified RDF (40 to 45 percent); small dense compostable fraction (25 to 30 percent); plastics (4 to 5 percent); cardboard (5 to 6 percent); ferrous metals (3 to 4 percent); and aluminum (1 percent). The remaining 10 to 15 percent is comprised of nonrecoverable materials which are disposed of in a landfill.

4.2.1.5 Fate of Separated Materials. The separated fine fraction, consisting of yard waste, glass, and grit is transported offsite to an outdoor composting area. Currently, the material is composted in a static pile, and the resulting compost is used as landfill cover. In the future, Reuter plans to use an indoor aerated windrow composting process which will compost the waste for 6 weeks. Mr. Markeson said that Reuter Recycling, Inc. may choose to screen out the glass, but will screen out household batteries and other contaminants, and the resulting compost may be used for agriculture or landscaping purposes. Mr. Markeson said that preliminary tests indicate that the metals content of the compost after screening would be low enough for agricultural use. He was not sure what would be done with the glass/contaminant fraction screened from the compost.

Separated aluminum is sold to a major aluminum producer, and ferrous scrap is sold to a scrap metals dealer. The ferrous scrap is then shredded prior to being sold to a steel manufacturer.

The PET plastics are granulated at the plant and sold to a company which uses the plastic to manufacture products such as polyester fiber insulation used in jackets and sleeping bags. The HDPE plastics are also granulated and sold to a company which uses the plastic to manufacture products such as plastic lumber and drainpipe. The LDPE film plastics are bailed and sold to the same company which uses the plastic to make new plastic film products.

Automotive batteries removed on the tipping floor are sold to a scrap dealer who sells them to a battery producer. The lead from the batteries is then processed into new batteries. Generally, less than a dozen batteries are separated per month.

Tires removed from the tipping floor are transported to a tire recycling facility in Minnesota. Reuter Recycling, Inc. pays a fee to the tire recycling facility for accepting the tires.

Corrugated paper materials separated on the tipping floor and at the handpicking station are bailed and sold to a corrugated paper producer. Textiles such as clothing, carpet, and upholstery, which are separated at the handpicking stations, are disposed of in a landfill with the other nonrecovered materials. Reuter Recycling, Inc. has not located an accessible market for used textiles.

The remaining separated paper fraction which is processed into bailed fluff RDF is given to an RDF combustion facility located in Minnesota and operated by Northern States Power. Northern States Power uses the bailed fluff RDF to balance energy inputs to their combustors when extra fuel is needed. The densified RDF pellets are sold to a paper manufacturing company as a fuel which is cofired with coal in traveling grate coal boilers. According to Minnesota State law, RDF can account for no more than 25 percent of the total Btu value when being cofired with coal.

4.2.1.6 Handpicking Operations. On the tipping floor, two to three workers pick out large appliances, tree limbs, automotive batteries, corrugated paper, and other large materials. There is a potential risk of accident. The workers walk through the garbage on the tipping floor as a front-end loader continually operates back and forth in the same area.

At the conveyor handpicking station, 15 to 20 workers remove aluminum, plastics, residual corrugated paper, and textiles from the waste. There are two separate processing lines with two conveyors per line (four conveyors total). Only large items removed on the tipping floor and the small, dense fraction are removed from the waste prior to entering the handpicking station. Ferrous materials are removed after the handpicking station.

The handpicking station is located in a glass-enclosed, climate-controlled room. The handpicking conveyor travels at a rate of 60 ft per minute, and workers pick materials at a very rapid rate. Some workers wear particle masks and others wear cloth laboratory coats, but some wear neither. All workers wear some sort of hand protection. Some wear cloth gloves while others wear heavy rubber gloves. Mr. Markeson expressed concern since workers had spotted some hypodermic needles in the waste stream. Mr. Markeson said that the company is looking into alternate types of gloves, such as leather, which could provide more protection against needles, but no decision has been made on a substitute. He added that their is a fairly high turnover rate for handpicking employees. About 70 handpicking employees (about 2 to 3 times the number employed at a given time) left the facility in 1988. However, there are opportunities for these workers to advance into other positions at the facility.

4.2.2 References for 4.2

1. Davis, L. Radian Corporation. Trip Report - Site Visit: Reuter Resource Recovery Materials Separation Facility. September 26, 1989.

5.0 IMPACTS OF MATERIALS SEPARATION ON COMBUSTOR AIR EMISSIONS, COMBUSTOR OPERATION, AND ASH

This section presents information on the effects of materials separation on MWC air emissions, combustor operation, and combustor ash. Section 5.1 presents information on the composition of typical MSW. Section 5.2 summarizes available information on the effect of materials separation on MWC air emissions including metals, organics, acid gases, and nitrogen oxide (NO_x). Section 5.3 describes potential beneficial effects of materials separation on combustor operations including the effects on operation and maintenance, combustor availability, productivity, and boiler efficiency. Section 5.4 presents information on the effects of materials separation on the quantity and quality of combustion.

5.1 COMPOSITION OF MUNICIPAL SOLID WASTE

Table 5-1 lists the components of typical MSW and the percent by weight of each component in the MWC.[1] Although the actual weight-percent of each component material will vary among communities and among seasons, the values presented are considered representative of MSW generated in the United States.

When considering the effects of materials separation, it is useful to classify MSW components into two categories, combustibles and noncombustibles. As shown in Table 5-1, paper and paperboard, plastics, yard waste, and food waste make up the majority of the combustible fraction of MSW. Glass and ferrous metals are the two largest noncombustible components, followed by aluminum and other nonferrous metals. During combustion, the combustible portion is burned and a volume reduction occurs. Although the noncombustible portion may be altered chemically and

TABLE 5-1. COMPOSITION OF MUNICIPAL SOLID WASTE[1]

Material	Percent by Weight in MSW[a]
Ferrous Metals	7.0
Aluminum	1.5
Other Nonferrous Metals	0.2
Glass	8.2
Miscellaneous Inorganic Wastes	1.6
TOTAL NONCOMBUSTIBLES	18.5
Paper and Paperboard	41.0
Plastics	6.5
Yard Waste	17.9
Food Waste	7.9
Wood	3.7
Rubber and Leather	2.5
Textiles	2.8
Other	0.1
TOTAL COMBUSTIBLES	82.4

[a] Percent of gross discards before materials recovery.

physically during combustion, and may affect MWC operation and emissions, it is not actually combusted.

Table 5-2 lists typical pollutants of concern from MWC's along with some common materials in MSW which are composed of the pollutant of concern or potential precursors for these pollutants. While this table does not list every component in MSW which potentially contributes to air pollution emissions, it does include the principal components. Section 5.2, which addresses the air emissions impacts from the separation of various components of MSW, includes a discussion of each of the two major categories of MSW and its potential contribution to air pollution emissions.

5.2 IMPACTS OF MATERIALS SEPARATION ON AIR EMISSIONS

This section summarizes test data and other information on the effects of materials separation and removal on air emissions from MWC's. In particular, the effects of removing noncombustibles, household batteries, lead-acid vehicle batteries, plastics, paper, and yard waste prior to combustion are discussed.

5.2.1 Noncombustibles

Noncombustibles comprise a broad class of waste components including metals, glass, grit, and other minerals. Noncombustible materials such as ferrous metals, glass, and aluminum do not directly produce potentially hazardous emissions. However, some ferrous items are associated with other heavy metals that can contribute to toxic emissions. For example, ferrous containers with lead-soldered seams, and ferrous components containing lead-soldered electrical junctions are sources of lead in MSW. Household batteries, which contain mercury, cadmium, and nickel, are often encased in steel jackets (see Section 7.0 for a discussion of household batteries).

Tests at three mass burn facilities, Gallatin, Tennessee; Nashville, Tennessee; and Salem, Virginia were conducted in a Department of Energy-sponsored study in association with NRT to evaluate the effect of noncombustibles removal on combustor performance and emissions. The Gallatin facility is an older (1981) Westinghouse/O'Connor technology mass burn rotary waterwall combustor with a capacity of 200 tpd. The

TABLE 5-2. PRINCIPAL COMPONENTS IN MSW WHICH POTENTIALLY CONTRIBUTE TO AIR POLLUTANT EMISSIONS FROM MWC'S[2,3,4]

Pollutant	Principal Components in MSW Composed of Pollutant or Pollutant Precursor
Cadmium	Nickel-cadmium batteries, plastics, plated metals, pigments
Lead	Lead-acid batteries, lead solder in consumer electronics, leaded ceramics, plastics, lead-soldered cans, pigments
Mercury	Dry cell batteries, electrical switches and relays, thermostats, paints, thermometers, fungicides, disinfectants
Hydrogen chloride (Cl)[a]	Chlorinated plastics, bleached paper, chlorinated solvents, yard wastes, food waste, miscellaneous organics
Sulfur dioxide (S)[a]	Cardboard and other paper, tires and other rubber, textiles, plastic, food waste, yard wastes, gypsum wallboard, miscellaneous organics
Nitrogen Oxide (N)[a]	Yard waste, food waste
Organic compounds	Organic chemicals, plastics, wood, paper, textiles, food waste, and all other organics

[a] Element in ( ) is contained in listed MSW component and is a precursor for associated pollutant.

Nashville facility is a relatively new (1986) B&W/Detroit Stoker excess air waterwall combustor with a capacity of 400 tpd. The total capacity at Nashville is 1,120 tpd. The Salem facility is an older Consumat Systems modular starved air combustor built in the early 1970's. The Salem facility consists of four 25 tpd combustors with a total capacity of 100 tpd.[5]

A MRF located in Gallatin and operated by NRT was used to separate noncombustibles from the waste for all three test sites. At the facility, the mechanical NRT separation process described in Section 3.0, was used to remove ferrous metals, nonferrous metals, and glass/grit.[6] Lead-acid vehicle batteries were removed by hand.[7] The MSW, from which most noncombustibles had been removed, referred to in the remainder of this section, as "separated MSW," was then returned to each MWC for incineration. Fuel composition for the three sites, before and after noncombustible separation, is shown in Table 5-3.[5] As-received waste at all three facilities contained about 70 to 76 percent combustible materials, while the separated MSW contained about 93 to 96 percent combustibles.

Uncontrolled emissions of heavy metals, carbon monoxide (CO), hydrocarbons, hydrogen chloride (HCl), sulfur dioxide (SO_2), and NO_x were measured at the three sites while burning as-received and separated MSW. Test results are presented in Tables 5-4 through 5-9.[6,8] Results are presented in terms of pounds (lbs) of pollutant per hour in the combustor exhaust gas, which is a measure of mass emissions, and as lbs of pollutant per 1,000 tons of as-received MSW, which is a measure of the total emissions exiting the combustor per ton of waste disposed. Measurements of gaseous pollutants are also given in parts per million by volume (ppmv) at 12 percent carbon dioxide (CO_2). These measurements were taken up-stream of add-on air pollution control devices, so they represent "uncontrolled" combustion outlet emissions rather than controlled stack emissions.

Results of measurements of uncontrolled particulate and heavy metal emissions at the Nashville MWC are shown in Table 5-4.[6] As shown in the table, particulate emissions are about 20 percent higher for separated

TABLE 5-3. SOLID WASTE FUEL COMPOSITION[5,6]

	As-received MSW			MSW Separated to Remove Noncombustibles		
	Gallatin 10/84	Nashville 04/87	Salem 05/86	Gallatin 10/84	Nashville 04/87	Salem 05/86
Combustibles	76.5%	74.5%	70.3%	93.3%	96.2%	94.0%
Metals	8.2%	7.0%	6.1%	2.4%	1.8%	1.3%
Glass	5.8%	7.3%	9.7%	1.7%	0.8%	1.9%
Grit	8.7%	10.4%	13.9%	2.6%	1.2%	2.8%
Oversize Bulky	0.8%	0.8%	-	-	-	-
Totals	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

TABLE 5-4. PARTICULATE AND HEAVY METAL EMISSIONS FROM THE NASHVILLE MWC[a,b]

	As-received MSW[c]		Separated MSW[d]	
	(lb/hr)	(lb/1,000 tons as-received MSW)[e]	(lb/hr)	(lb/1,000 tons as-received MSW)[f]
Filterable Particulates	233	14,617	326	17,489
Arsenic	0.035	2.2	0.039	2.1
Beryllium	0.009	0.56	<0.0002	<.01
Cadmium	0.240	15.1	0.156	8.4
Chromium	0.039	2.5	0.079	4.2
Copper	0.296	18.6	0.289	15.5
Lead[g]	4.264	268	4.304	231
Manganese	0.290	18.2	0.433	23.2
Nickel	0.021	1.32	0.092	4.94
Tin	0.872	54.7	0.429	23.0
Vanadium	0.044	2.76	0.071	3.81
Zinc	12.11	760	8.27	444
Mercury	0.194	12.2	0.065	3.49

[a] Reference 6.

[b] Heavy metals testing was performed according to EPA Method 5. Mercury testing was performed according to Method 101A.

[c] Measurements are averages of three test runs. Runs were conducted on February 9, 10, and 11, 1984.

[d] Measurements are averages of three test runs conducted on April 15, 1984.

[e] Based on an average of 15.94 tons of as-received MSW combusted per hour.

[f] Based on an average of 18.64 tons of as-received MSW (total MSW before processing) disposed per hour.

[g] Lead-acid vehicle batteries were not removed from the separated MSW.

TABLE 5-5. GASEOUS EMISSIONS FROM THE NASHVILLE MWC[a,b]

	As-Received MSW[c]			Separated MSW[d]		
	(lb/hr)	(ppmv)[e]	(lb/1,000 tons as-received MSW)[f]	(lb/hr)	(ppmv)[e]	(lb/1,000 tons as-received MSW)[g]
Carbon monoxide	6.0	33	374	3.16	19.4	170
Nitrogen oxide	43.2	147	2,711	54.8	204.3	2,940
Sulfur dioxide	40.6	107	2,547	52.8	141.5	2,832
Hydrogen chloride	145	643	9,096	78.8	493.6	4,227
Total Hydrocarbons	0.89	13	56	0.92	13.2	49

[a] Reference 6.

[b] Emissions of CO, NO_x, SO_2, and total hydrocarbons are based on continuous emission monitor (CEM) measurements. Hydrogen chloride measurements are averages of three measurements conducted according to EPA Method 13A.

[c] As-received MSW measurements conducted on February 9, 10, and 11, 1984.

[d] Separated MSW measurements conducted on April 15, 1984.

[e] Parts per million by volume at 12 percent CO_2.

[f] Based on an average of 15.64 tons of as-received MSW combusted per hour.

[g] Based on an average of 18.64 tons of as-received MSW disposed per hour.

TABLE 5-6. HEAVY METAL EMISSIONS FROM THE SALEM MWC[a,b]

	As-received MSW[c]		Separated MSW[d]	
	(lb/hr)	(lb/1,000 tons as-received MSW)[e]	(lb/hr)	(lb/1,000 tons as-received MSW)[f]
Arsenic	0.0029	1.0	0.0010	0.3
Cadmium	0.0149	5.4	0.0138	4.2
Chromium	0.0002	0.07	0.0003	0.09
Lead[g]	0.1025	36.8	0.1260	38.6
Mercury	0.00007	0.025	0.0003	0.09

[a] Reference 6.

[b] Heavy metals testing was performed according to EPA Method 5. Mercury testing was performed according to Method 101A.

[c] Measurements are averages of six test runs conducted during May 12 and 13, 1986.

[d] Measurements are averages of six test runs conducted during May 19 and 20, 1986.

[e] Based on an average of 2.79 tons of as-received MSW combusted per hour.

[f] Based on an average of 3.27 tons of as-received MSW disposed per hour.

[g] Lead-acid vehicle batteries were removed from the separated MSW.

TABLE 5-7. GASEOUS EMISSIONS FROM THE SALEM MWC[a,b]

	As-Received MSW[c]			Separated MSW[d]		
	(lb/hr)	(ppmv)[e]	(lb/1,000 tons as-received MSW)[f]	(lb/hr)	(ppmv)[e]	(lb/1,000 tons as-received MSW)[g]
Carbon monoxide	-	2.8[h]	-	-	15.9[h]	-
Nitrogen oxide	8.6	87	3,104	7.7	78	2,370
Sulfur dioxide	5.45	54.9	1,952	6.72	67.9	2,055
Hydrogen chloride	3.0	54	1,095	0.74	13.2	228
Total Hydrocarbons	-	9.3[i]	-	-	29.2[i]	-

[a] Reference 8.

[b] Emissions of NO_x based on CEM measurements. Emissions of SO_2 conducted according to EPA Method 8. Emissions of HCl conducted according to EPA Method 6.

[c] As-received MSW measurements conducted May 12 and 13, 1986.

[d] Separated MSW measurements conducted May 19 and 20, 1986.

[e] Parts per million by volume at 12 percent CO_2.

[f] Based on an average of 2.79 tons of as-received MSW combusted per hour.

[g] Based on an average of 3.27 tons of as-received MSW disposed per hour.

[h] Instrument failure resulted in invalid CEM measurement for CO. Emission data result of grab samples.

[i] Instrument failure resulted in invalid CEM measurement for total hydrocarbons. Emission data are result of grab samples.

TABLE 5-8. HEAVY METAL EMISSIONS FROM THE GALLATIN MWC[a,b]

	As-received MSW[c]		Separated MSW[d]	
	(lb/hr)	(lb/1,000 tons as-received MSW)[e]	(lb/hr)	(lb/1,000 tons as-received MSW)[f]
Arsenic	0.012	3.2	0.008	2.1
Cadmium	0.088	23.6	0.025	6.4
Chromium	0.029	7.9	0.011	2.9
Lead[g]	1.02	274	0.530	130

[a] Reference 6.

[b] Heavy metals testing was performed according to EPA Method 5.

[c] Measurements are averages of three test runs conducted during February 7 - 11, 1983.

[d] Measurements are averages of three test runs conducted during February 10, 1983, and three test runs conducted on October 8, 1984.

[e] Based on an average of 3.74 tons of as-received MSW combusted per hour.

[f] Based on an average of 4.50 tons of as-received MSW disposed per hour.

[g] Lead-acid vehicle batteries were removed from the separated MSW.

TABLE 5-9. GASEOUS EMISSIONS FROM THE GALLATIN MWC[a,b]

	As-Received MSW[c]			Separated MSW[d]		
	(lb/hr)	(ppmv)[e]	(lb/1,000 tons as-received MSW)[f]	(lb/hr)	(ppmv)[e]	(lb/1,000 tons as-received MSW)[g]
Carbon monoxide	17.9	540	4,490	7.16	216	1,590
Hydrogen chloride	19.8	509	5,300	27.9	721	6,200
Sulfur dioxide	11.41	182	2,810	12.47	199	2,779
Nitrogen oxide	9.11	147	2,200	5.76	93	1,280
Nonmethane hydrocarbons	1.09	40.5	230	0.27	10.0	60

[a] Reference 6.

[b] Emission data for CO, SO_2, NO_x, and nonmethane hydrocarbons are based on CEM measurements. Emission data for HCl are based on sampling with a multiclone train and ion chromatography analysis.

[c] As-received MSW measurements conducted February 7 - 23, 1983.

[d] Separated MSW measurements conducted February 7 - 23, 1983, and on October 8, 1984.

[e] Parts per million by volume at 12 percent CO_2.

[f] Based on an average of 3.74 tons of as-received MSW combusted per hour.

[g] Based on an average of 4.50 tons of as-received MSW disposed per hour.

waste than for as-received MSW. On a mass emissions basis, beryllium, cadmium, copper, tin, zinc, and mercury emissions are higher for the as-received MSW. Mass emissions of arsenic, chromium, lead, manganese, nickel, and vanadium are higher for the separated MSW.

When comparing emissions from the Nashville MWC on a lb of pollutant per 1,000 tons of as-received MSW basis, emissions of arsenic, beryllium, cadmium, copper, tin, zinc, and mercury are higher for the as-received waste while emissions of chromium, manganese, nickel, and vanadium are higher for the separated waste. When measured on a lb of pollutant per ton of as-received MSW basis, emission values are based on the amount of as-received MSW received for each test. For the separated MSW, the amount received is greater than the amount actually combusted because some is removed during processing. For the Nashville tests of as-received MSW, 15.94 tons of as-received MSW were combusted per hour. However, for the tests of the separated MSW, the emission values are based on 18.64 tons as-received MSW combusted per hour. Of the 18.64 tons, 13.89 tons were actually combusted per hour, and 4.75 tons were separated prior to combustion per hour. Lead-acid vehicle batteries were not removed from the separated MSW combusted during the Nashville tests.

Results of measurements of uncontrolled gaseous emissions at the Nashville MWC are presented in Table 5-5.[6] This table shows that emissions of NO_x and SO_2 were higher for the separated MSW regardless of the basis for measurement, while emissions of CO and HCl were higher for the as-received MSW. Emissions of total hydrocarbons were slightly higher for the separated MSW on a mass emissions and a concentration basis, but slightly lower for the separated MSW on a lb of pollutant per 1,000 tons of as-received MSW basis.

While the data may indicate that some heavy metals and gaseous emissions are higher or lower for combustion of as-received MSW as compared to separated MSW, these data are not conclusive. At Nashville, testing of emissions from combustion of as-received MSW was conducted in February 1984, while testing of emissions from combustion of separated MSW was conducted in April 1984. Since waste stream characteristics vary considerably from season to season, as well as from day to day, it is difficult to compare emissions from waste combusted several months apart.[6]

Test results of heavy metal emissions from the Salem MWC are shown in Table 5-6.[6,8] At Salem, arsenic, cadmium, and mercury emissions were higher for combustion of the as-received MSW on both a mass emissions basis and a lb of pollutant per 1,000 tons of MSW disposed basis. However, emissions of chromium and lead were higher for combustion of the separated MSW. Lead-acid vehicle batteries were removed from the separated MSW at Salem.

Table 5-7 shows that emissions of NO_x and HCl at Salem are higher for the as-received MSW, whereas emissions of SO_2 are higher for the separated MSW.[6,8] Average emissions for CO and total hydrocarbons are not presented because of instrument failures encountered during testing. However, grab samples showed that both CO and total hydrocarbons were higher for the separated MSW.

At Salem, emissions testing for as-received MSW was conducted May 12 and 13, 1986, and testing for separated MSW was conducted May 19 and 20, 1986. While all of the as-received MSW was derived from the Salem, Virginia, area, the separated MSW combusted during testing was not all derived from the Salem area MSW. At least 50 percent of the separated MSW combusted during testing was derived from Gallatin, Tennessee, area waste. The remainder of the separated waste was Salem area waste which was shipped to Gallatin, Tennessee, for processing and then returned for combustion testing.[6]

Since the two types of waste used in combustion testing at Salem were not always derived from the same community, and since it is possible that differences in MSW characteristics from the two regions are significant, it is not possible to determine whether differences in emissions are a result of MSW separation or differing waste stream composition.

Table 5-8 presents uncontrolled heavy metals emissions from the Gallatin MWC while burning as-received and separated MSW.[6] For each metal measured (arsenic, cadmium, lead, and chromium), emissions were higher for the as-received MSW. Lead-acid vehicle batteries were removed from the separated MSW of Gallatin. Emissions of gaseous pollutants from the Gallatin MWC are shown in Table 5-9.[6] Emissions of CO, NO_x, and nonmethane hydrocarbons are much higher for the as-received MSW. Sulfur dioxide emissions are very similar for the as-received and separated MSW, while HCl emissions are higher for the separated MSW.

At Gallatin, measurements for the as-received MSW were conducted in February 1983, while measurements for the separated MSW were conducted in February 1983 and later in October 1984. Again, the validity of comparing results of separate emissions tests conducted more than a year apart using waste derived during different seasons is questionable.[6]

In examining the emissions measurements from the three test sites, it appears that in many cases, heavy metals emissions were lower when combusting separated MSW; however, in other cases heavy metals emissions were higher for the separated MSW. Cadmium emissions appear to be somewhat lower for separated waste at all three test sites, but results for lead and mercury are mixed. Results for each of the gaseous pollutants, CO, NO_x, SO_2, HCl, and hydrocarbons were mixed, and no clear trend can be identified.

Uncontrolled emissions from MWC's are typically variable due to the highly variable nature of MSW. As previously discussed, each of the three tests were conducted using as-received MSW or separated MSW collected during different times of the year or from different localities. These testing practices are likely to have contributed significantly to variations in emissions results from combustion of the two types of MSW. Also, combustors operated at different temperatures for different types of MSW, and this could also be a source of variability. In many cases, results are based on as few as three test runs for as-received MSW and three test runs for separated MSW. The small number of data points does not allow for an extensive analysis. Therefore, while it would seem to be a straightforward conclusion that removal of noncombustibles would result in a reduction in uncontrolled metals emissions, current data are limited.

Add-on particulate matter (PM) control devices such as electrostatic precipitators (ESP's) and fabric filters (FF's), required under the proposed regulations for new and existing MWC's, typically reduce metals emissions by over 97 percent, with the exception of mercury. Since these add-on control devices already achieve a substantial reduction in metals emissions, any reductions in uncontrolled metals emissions achieved through materials separation would have a small incremental effect in reducing stack emissions.

5.2.2 Household Batteries

It is estimated that over 2.5 billion household batteries are purchased each year to power flashlights, toys, cameras, appliances, and other electrical products.[9] Many common types of batteries contain high amounts of mercury, cadmium, and/or nickel. The burning of these batteries may contribute to mercury and cadmium air emissions from MWC's. Some of the household batteries present in MSW were removed magnetically with the noncombustible materials in the three tests described in Section 5.2.1, and it is possible that in some cases their removal may have contributed to reductions in mercury, cadmium, and other metals. However, there are no data to demonstrate what quantity of mercury, cadmium, or other metal emissions from MWC's are due specifically to the combustion of batteries. Section 7.0 discusses the composition of batteries as well as current separation efforts.

5.2.3 Lead-Acid Vehicle Batteries

Lead-acid vehicle batteries are the single most prevalent source of lead introduced into the solid waste stream. In 1985, lead-acid vehicle batteries accounted for 73 percent of the lead used in the United States.[9] Lead-acid vehicle batteries are the large batteries used in automobiles, boats, lawn tractors, farm and construction machinery, and other vehicular and stationary uses. These batteries are composed of about 50 percent by weight of lead (approximately 18 lbs of lead per battery). In 1986, about 70 percent of all used lead-acid vehicle batteries in the United States were recycled. The remainder accounted for over 185,000 tons of lead discarded into the MSW stream or elsewhere.[9]

Recycling of lead-acid vehicle batteries has decreased in the past 20 years (see Figure 5-1). In the mid-1960's, over 97 percent of all lead-acid vehicle batteries were recycled. The decline is attributed to the increased cost to recyclers for compliance with occupational health and environmental regulations and to decreased demand for lead due to the elimination of lead in gasoline and most paints.[9,10,11]

Studies conducted at the Gallatin MRF over a 3-month period in 1987, in which lead-acid vehicle batteries were selectively removed by hand and weighed, found that 1,265 lbs of lead in the form of batteries were removed from 6,065 tons of MSW. This results in an average of 104 ppm of lead removed.[12] This amount is equal to over half of the average total lead content in as-received MSW measured in the combustor exhaust and the ash at the three test facilities discussed in Section 5.2.1. Based on this test, separation of lead-acid batteries could significantly reduce the amount of lead in MSW, and thereby potentially reduce lead emissions. However, from the air emissions values presented in Section 5.2.1, the effect of lead-acid vehicle battery removal is not clear. Emissions of lead were higher for separated MSW at Salem and higher for unseparated MSW at Gallatin. Lead-acid vehicle batteries were removed from separated MSW for both tests. For the Nashville test, where lead-acid vehicle batteries were not separated for the separated MSW, there was little difference in lead emissions for separated and unseparated MSW.

5.2.4 Plastics

Plastics are an increasing constituent in the MSW stream. Polyvinyl chloride (PVC) is the most prevalent chlorine-containing plastic in MSW and has been shown to be a precursor for formation of chlorinated dibenzo-p-dioxins and dibenzo-furans (dioxin/furan) in laboratory tests.[13] However, its role in dioxin/furan emissions from MWC's is not clear. Studies at the Pittsfield, Massachusetts, MWC showed that levels of dioxin/furan at the boiler and stack outlets were not significantly affected by the amount of PVC in the waste feed.[14]

It is believed that dioxin/furan precursors are diverse in the MSW stream. Also, since chlorine-containing materials are dispersed throughout the waste stream, and since the concentration of chlorine in the combustion gas stream is generally several thousand times greater than concentrations of dioxin/furan, it is doubtful that separating any specific chlorine-containing material will sufficiently lower the level of available chlorine to a point where dioxin/furan formation is limited.[15]

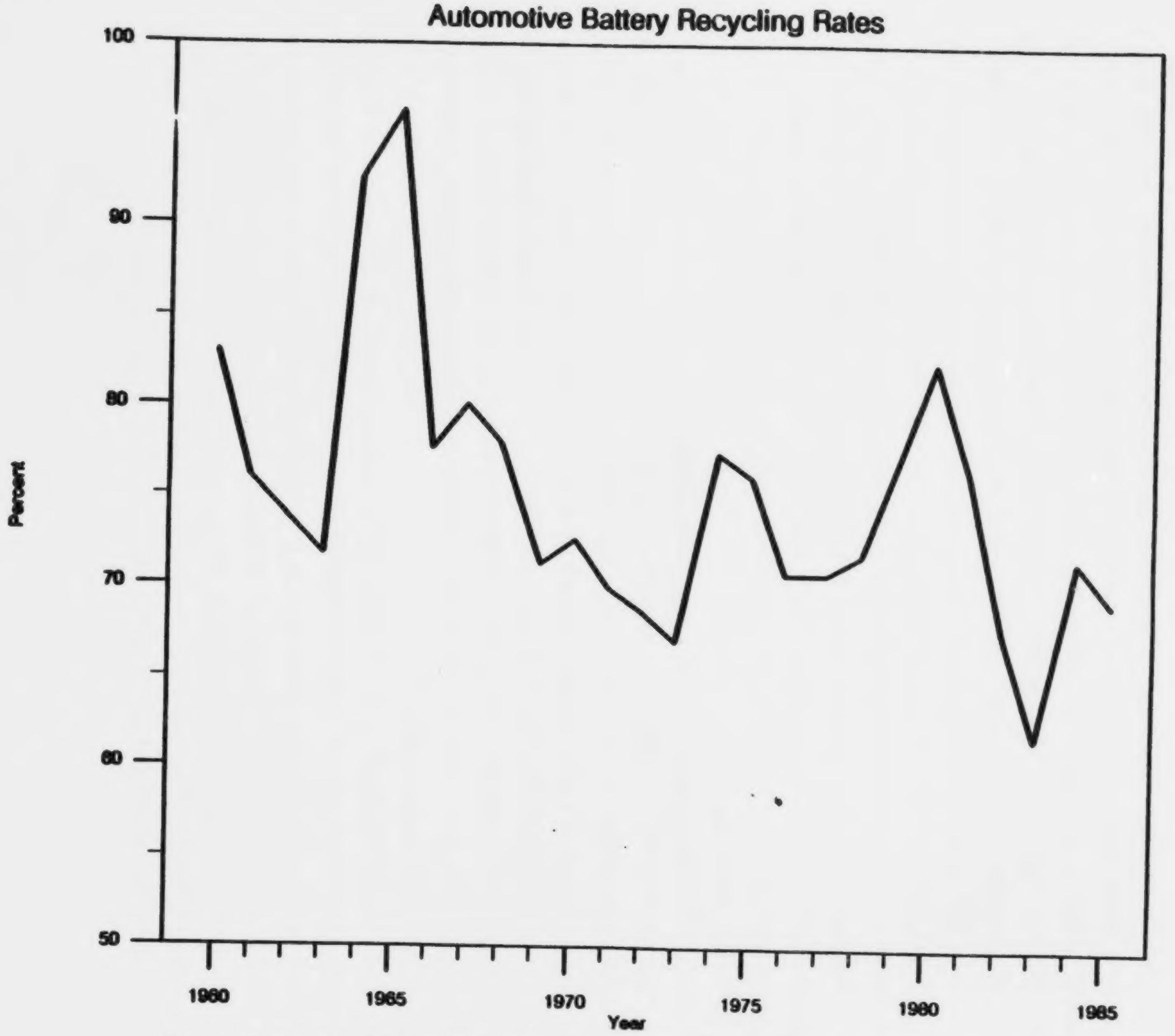

Figure 5-1. The Rate of Lead-Acid Battery Recycling in the U.S. from 1960-1985 [9]

Studies at Pittsfield, Massachusetts, however, did show that the concentration of HCl in the flue gas stream was correlated with the amount of PVC in the waste that was combusted. Therefore, separation of PVC may help to reduce HCl emissions from MWC's.[14]

5.2.5 Paper

Paper products comprise the largest segment of MSW and are the primary fuel source in the incineration of MSW. Paper products, especially bleached paper, are sources of chlorine, but it is not clear to what extent removal prior to combustion would reduce HCl emissions since chlorine is distributed throughout the combustible waste fraction. Corrugated paper has a relatively high sulfur content, and its removal theoretically could reduce combustor SO_2 emissions.[4]

Paper products are also potential sources of heavy metals such as chromium, lead, and cadmium since paper products are often imprinted with inks and other colorants containing high concentrations of these materials. Separation of some paper may, therefore, help to reduce heavy metal emissions. The waste paper fraction has a heating value of about 8,000 Btu/lb compared to about 4,500 Btu/lb for the total MSW stream.[11] If a high proportion of paper were removed, the heating value of the fuel would be less and combustion performance may decline, possibly resulting in higher emissions of some pollutants. No data are available on the positive or negative effects of paper separation on MWC emissions.

5.2.6 Yard Wastes

Yard waste (leaves, grass clippings, and brush) is the second most prevalent constituent of MSW behind paper.[1] The degree of moisture in yard waste varies greatly depending on season and location. As a result, yard waste exhibits inconsistent combustibility which may hinder combustion performance and potentially contribute to products of poor combustion such as organic compounds. However, there are no data relating removal of yard waste to toxic emissions.

Yard wastes, especially grass clippings, are a source of nitrogen in MSW, and it is an established fact that NO_x emissions from combustion are related to the nitrogen content of the fuel. Testing at mass burn MWC's has shown that NO_x emissions increase during the summer months when the MSW contains a higher proportion of yard waste.[16] The exclusion of yard wastes from combustion may, therefore, reduce NO_x emissions.

5.3 IMPACTS OF MATERIALS SEPARATION ON COMBUSTOR OPERATIONS

This section discusses the effects of separation and removal of noncombustible and combustible materials on MWC operation. Materials separation may affect equipment life, frequency of operation and maintenance problems, combustor availability, steam production, and boiler efficiency.

5.3.1 Noncombustibles

Theoretically, the removal of noncombustibles would not adversely affect the combustion process. Removal of glass, metals, and grit should decrease slag and clinker formation. Slag is a rock-like mineral material formed by the melting and subsequent solidification of ash in a furnace. A clinker is a large solidified mass of slag material. Reductions in slag and clinker formation would reduce maintenance, increase equipment life, increase combustor availability, and improve performance.[13,17] Aluminum can melt and block underfire air plenums in the boiler, causing uneven burning. Removal of aluminum could result in improved combustor efficiency.[18] Removal of noncombustible materials would also tend to increase the heating value of MSW, resulting in increased boiler efficiency.

Boiler efficiency and MWC operations were studied at the Gallatin, Tennessee, mass burn rotary waterwall MWC. A mechanical separation process to remove noncombustible materials was installed at Gallatin in 1982 (see Section 4.0 for a description of the NRT separation process). During a 19-day test in August 1983, one unit was operated using separated MSW, while the other unit was operated using as-received MSW. During the periods before and after the test, both units used mostly separated MSW.

Combustor availability (percent of time combustor operated) was recorded over a 9-week period before, during, and after the test. When the separated MSW was fired, combustor availability was about 80 to 86 percent, whereas when as-received MSW was fired, availability decreased to about 60 percent. Decreased ash drag failure, hopper jam, and decreased episodes of low steam pressure were observed while the separated MSW was fired.

Information collected over a 3-year period indicates that combustor downtime was reduced by about 20 percent after the separation process was installed.[12]

Greater steam production resulted at the Gallatin MWC from increased combustor availability when combusting the separated MSW. When burning as-received MSW, an average of about 2.80 lb of steam were produced per lb of waste received. When burning 70 percent separated MSW fuel, steam production was about 2.94 lb/lb of MSW received at the processing facility (3.2 lb/lb of separated waste combusted).[12] When burning 100 percent separated MSW, a rate of 3.07 lb/lb of waste received is predicted from the available data.[19] A 12 percent increase in steaming rate, expressed as lb/hr of steam produced during combustion, was observed when combusting separated MSW.[19] Long-term data show an increase in steam sales of over 30 percent since the Gallatin MWC began combusting separated MSW in March 1982.[12]

Furnace temperature profiling was performed in February 1983 tests. Temperatures were measured along a vertical plane through the centerline of the furnace oriented to contain the rotation axis of the combustor. Average furnace temperatures (4-hour averages) in the measured locations were found to be higher by about 80°F to 200°F in five of the six measured locations when the combustor was burning separated MSW. In the sixth location, the temperature was about 30°F higher when the combustor was burning as-received MSW.[18]

Removal of noncombustibles increased the heating value of the MSW at the three sites by 18 to 32 percent.[5] Increased heating values would lead to more efficient combustion.

During the more recent tests at Gallatin, Tennessee; Nashville, Tennessee; and Salem, Virginia, described in Section 5.2.1, effects of materials separation on MSW disposal rates and boiler efficiency were measured. The average disposal rates (tons of as-received MSW disposed per hour) increased by 14 to 24 percent for the three MWC's, as shown in Table 5-10.[19]

Boiler efficiency tests were performed using American Society of Mechanical Engineers (ASME) procedures. The test data are shown in

TABLE 5-10. MUNICIPAL SOLID WASTE DISPOSAL RATES[19]
(Includes materials removed in processing)

	Combustor Fired On As-Received MSW (tons/hour)	Combustor Fired on MSW Separated to Remove Noncombustibles (tons/hour)	Percent Increase
Gallatin, TN	3.25	4.03	24
Nashville, TN	15.96	18.12	14
Salem, VA	2.79	3.27	17

Table 5-11.[5] When firing separated MSW, boiler efficiency increased at all three sites, ranging from a 1.6 percent increase at Nashville to a 10.6 percent increase at the older Salem MWC. At Nashville, the increase in efficiency was due mainly to increased ash burnout. At Gallatin, reduced water losses and dry gas losses, in addition to increased ash burnout accounted for a 6.0 percent increase in boiler efficiency. However, it should be noted that efficiency testing at Gallatin for as-received MSW and separated MSW was performed using different methods. Therefore, it may not be valid to compare these results. The major contributors to increased efficiency at Salem appear to be reduced dry gas losses and water losses.

Efficiency calculations are highly dependent on furnace excess air levels. If operating conditions are not held constant among test runs, the data cannot be reliably compared. At this point, it is unclear whether differences in operating conditions may have affected the results of boiler efficiency testing at the three test sites.

In summary, while data are limited, the available data tend to support the expectation that removal of noncombustible materials should improve combustor operation. However, a more thorough analysis of the available data is recommended.

5.3.2 Combustibles

Removal of combustible materials, such as paper and plastics, would remove constituents of the waste capable of supporting combustion. If a heat content high enough to support combustion is not maintained, the addition of fossil fuel may be required to carry out the combustion process and to maintain temperatures sufficient for the destruction of organics.

Paper generally has a heating value of about 8,000 Btu/lb and plastics a heating value of about 12,000 Btu/lb. In comparison, the heating value for total MSW is about 4,500 Btu/lb.[13] Thus, removal of too much of the paper fraction could reduce the heating value of the MSW significantly.

The effect of materials separation on the fuel value of MSW has been studied by Wheelabrator, Inc., a major manufacturer of waste combustion equipment. According to this manufacturer, an all-encompassing materials

TABLE 5-11. BOILER EFFICIENCY MEASUREMENTS[5,6]

	Combustor Fired On As-Received MSW			Combustor Fired on MSW Separated to Remove Noncombustibles		
Test No.	Gallatin	Nashville	Salem	Gallatin	Nashville	Salem
1	62.5%	67.3%	50.0%	68.3%	71.2%	56.7%
2	63.8%	70.5%	60.0%	70.0%[a]	70.9%	63.4%
3	70.8%	33.7%			59.0%	
4		48.4%			55.2%	
Average	63.2%	69.5%	48.0%	69.2%	71.1%	58.6%
Heat Losses						
Dry Flue Gas	13.2%	14.2%	21.0%	11.9%	14.1%	16.5%
Fuel Moisture	4.0%	4.6%	5.2%	3.5%	4.2%	4.5%
$H_2 \rightarrow H_2O$	9.5%	8.4%	13.1%	7.9%	8.3%	9.4%
Ash Burnout	5.5%	1.5%	6.2%	3.2%	0.5%	5.3%
Other	5.3%	1.8%	6.5%	5.2%	1.8%	5.8%

[a] Test No. 2 at Gallatin was an input/output test determined by long-term analysis of steam production correlated with waste input and materials recovery activities over a 2-year period.

separation/recycling program that removes both combustibles and noncombustibles should not appreciably alter the fuel value of the incoming waste. The removal of noncombustibles (i.e., glass, metal cans, etc.) would have no effect on thermal input. Enough paper should remain after recycling to maintain present levels of electricity and steam production with no requirement for auxiliary fuel. Another study estimates that a newspaper recycling program achieving 25 percent participation would reduce the fuel value of the remaining waste by only 2.8 percent.[20]

While yard waste is a combustible material, it typically contains so much moisture that combustion is poorly sustained. Therefore, removal of yard waste or other wet organic waste is generally considered to be beneficial to combustor operation.[13]

5.4 IMPACT OF MATERIALS SEPARATION ON ASH QUANTITY AND QUALITY

The combustion of MSW generally produces two types of residue, bottom ash which is collected from the combustor, and fly ash which is removed from the flue gas stream by add-on APCD's. The ash is composed mainly of noncombustible materials, and typically contains heavy metals such as lead, cadmium, and mercury. The concentration of leachable heavy metals in MWC ash, especially lead and cadmium, is a concern in disposing of ash in landfills, because leachate, if not contained, could impact water quality.[21] The toxicity of ash is also of concern because fugitive air emissions occur during handling, storage, and transportation of ash. This section summarizes information on the effects of materials separation on ash quantity and quality.

5.4.1 Noncombustibles

Since noncombustible materials (glass, ferrous and nonferrous metals, and grit) are not reduced in weight or volume by the combustion process, essentially 100 percent of the noncombustible materials entering the MSW become ash. In contrast, proximate analyses show that only about 5 percent (dry basis) of paper is ash. Therefore, reducing the amount and relative proportion of noncombustibles entering the MWC would reduce ash generation.

Test data from the Gallatin, Tennessee; Nashville, Tennessee; and Salem, Virginia, MWC's described in Section 5.2 support this conclusion. Data are available comparing the waste composition and quantity of ash generated when burning as-received MSW versus MSW separated to remove noncombustible materials.

The proximate analysis of the MSW showed that the ash content of the MSW at all three facilities was reduced by about 50 percent due to the removal of noncombustibles. The ash content of as-received MSW averaged 23 to 25 percent, whereas the ash content of the separated MSW was 10 to 13 percent.[5] The amount of bottom ash produced per ton of MSW combusted was reduced by 45 to 50 percent for all three facilities. When burning as-received MSW, about 0.20 to 0.23 tons of bottom ash were produced per ton of MSW combusted, but when burning waste from which noncombustibles had been removed, about 0.10 to 0.12 tons of ash were produced per ton of waste combusted.[5] More complete ash burnout indicated by a lower carbon content in the ash was also observed at Nashville and Gallatin. At Salem, ash burnout was not particularly good for either as-received MSW or separated MSW. It is believed that poor ash burnout was due to the high proportion of tires in the Salem waste since the Salem MWC accepts tire waste from a nearby manufacturer. The exact percent reductions in ash quantity achievable through removal of noncombustibles would vary depending on site-specific waste composition and the amount of noncombustible materials removed.

Removal of heavy metals present in the noncombustible fraction of MSW would be expected to reduce the amount of metals in MWC ash. Data on the leachable heavy metal content of the bottom ash (lb metal per 1,000 tons as-received MSW) and the corresponding extraction procedure (EP) toxicity measurements (ppm of extract) were gathered during the tests of the Nashville and Salem MWC's. These data were not collected at Gallatin. Tables 5-12 and 5-13 show the results.[5] These measurements showed reduction in leachable lead for both facilities, but increases in cadmium. There was no measurable change for most other metals because levels found at both MWC's for both separated and as-received MSW were below the analytical detection limit.

Lead in ash, measured as ppm of extract and as lbs of leachable heavy metals per ton of MSW combusted, was about 80 percent lower at Nashville and about 30 percent lower at Salem for combustion of separated MSW.

TABLE 5-12. BOTTOM ASH EP TOXICITY MEASUREMENTS[5,6]

	Combustor Fired On As-Received MSW (ppm of extract)		Combustor Fired On MSW Separated to Remove Noncombustibles (ppm of extract)	
	Nashville[a] 04/87	Salem[b] 05/86	Nashville[a] 04/87	Salem[b] 05/86
Lead	2.42	15.20	0.69	12.30
Cadmium	0.10	0.21	0.42	0.28
Silver	0.02	0.02	0.03	0.01
Mercury	<0.0020	<0.0020	0.0028	<0.0020
Arsenic	<0.03	<0.03	<0.03	<0.03
Chromium	<0.04	<0.02	<0.04	<0.03
Barium	<0.50	none	<0.50	none
Selenium	<0.01	<0.01	<0.01	<0.01

[a] Nashville values are averages of six measurements for as-received MSW, four measurements for separated MSW.

[b] Salem values are averages of two measurements each for as-received MSW and separated MSW.

TABLE 5-13. BOTTOM ASH LEACHABLE HEAVY METALS[5,6]

	Combustor Fired On As-Received MSW (lbs/1,000 tons as-received MSW Combusted)		Combustor Fired On MSW Separated to Remove Noncombustibles (lbs/1,000 tons Separated MSW Combusted)	
	Nashville[a] 04/87	Salem[b] 05/86	Nashville[a] 04/87	Salem[b] 05/86
Lead	27.3	287	5.33	201
Cadmium	1.13	3.98	3.25	4.63
Silver	0.226	0.28	0.232	0.16
Mercury	<0.023	<3.8E-04	0.021	<3.8E-04
Arsenic	<0.338	<0.57	<0.338	<0.57
Chromium	<0.451	<0.38	<0.451	<0.38
Barium	<5.64	none	<5.64	none
Selenium	<0.113	<0.19	<0.113	<0.19

[a] Nashville values are averages of six measurements for as-received MSW, four measurements for separated MSW.

[b] Salem values are averages of two measurements each for as-received MSW and separated MSW.

Removal of lead-acid vehicle batteries may account for some of the lead reductions at Salem, but lead-acid vehicle batteries were not removed from the separated MSW at Nashville. While the lead concentration in the ash from Salem is much higher than that from Nashville, the uncontrolled lead air emissions (see Tables 5-12 and 5-13) are much higher for Nashville. These results indicate that the excess air combustion at the Nashville MWC may be more effective at volatilizing lead than the smoldering type of combustion at the Salem starved-air MWC.

In contrast, the cadmium content of ash increased while burning the separated MSW at both the Nashville and Salem facilities. The reasons for the increases in cadmium are uncertain. Removal of cadmium-containing batteries would generally help reduce the amount of cadmium in ash, but since these batteries are often encased in appliances, it is not known how many are removed magnetically in the separation process.

At Nashville, the concentration of mercury in the ash from separated MSW was slightly above the detection limit while mercury in the ash from as-received MSW was below the detection limit. At Salem, mercury was below the detection limit for both types of MSW. There was little difference in the silver concentration in the ash from the two types of MSW. Since measurements for arsenic, chromium, barium, and selenium were below the detection limit, no comparison can be made for these metals.

The concentrations of heavy metals in fly ash collected by a control device would theoretically be reduced if combustor outlet emissions of metals relative to PM were reduced; however, as discussed in Section 5.3, the data concerning the concentrations of metals in combustor outlet emissions are inconclusive. No EP toxicity test data were collected on the fly ash at Nashville or Salem.

As discussed in Section 5.3 with regard to air emissions for the three test sites, variations in the composition of waste used during the tests could possibly account for variations in the metals content measured in the ash.

5.4.2 Combustibles

Removal of combustibles would have a lesser effect on the quantity and quality of MWC ash. Only a small percent of the combustible materials remains as ash. Proximate analyses of various types of plastics, paper, textiles, food, and yard waste shows that the ash content (dry basis) of these materials ranges from about 2 to 20 percent, with yard waste being at the upper end of the range.[18]

Reductions in the amount of combustibles burned, especially yard waste, could reduce ash quantity somewhat. However, if a high proportion of combustible materials were removed, increased ash generation per ton of waste combusted could result, due to the higher proportional concentration of noncombustibles which become ash. Operating problems such as decreased combustibility discussed in Section 5.3 could also result. Therefore, a balanced removal program is preferable.

To the extent that combustibles contain heavy metals (e.g., metals in printing inks used on paper), removal of some combustibles could result in improved ash quality, however, no data are available indicating the effect of separation of combustible materials on ash quality.

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6.0 OCCUPATIONAL RISKS FOR MANUAL SEPARATION OF RECOVERABLE MATERIALS

6.1 INTRODUCTION

Manual separation (handpicking) of recoverable materials is a technique that may be used to comply with the materials separation provisions of the standards and guidelines for MWC's proposed on December 20, 1989. The case studies presented in Sections 3.2, 3.3, 3.4, 4.1, and 4.2 include handpicking as part of the materials separation process. The occupation of handpicking at MRF's is a relatively new one. This occupation involves the removal of various recyclable materials such as metals, paper, glass, cardboard, plastics, automobile batteries, and large pieces of wood from the MRF feed stream. No studies were found documenting safety and health hazards associated with handpicking at MRF's. However, studies have been performed to evaluate occupational risks associated with the handling of municipal wastes, in particular, sanitation workers (individuals who empty cans of MSW into trucks). Since both occupations are similar in that they require the handling of MSW, injuries and other problems associated with handpickers should be similar to those encountered by sanitation workers. By examining the occupational risks associated with sanitation workers, inferences can be drawn to determine potential health and safety hazards related to handpicking at MRF's. In order to obtain information on occupational risks associated with the handling of MSW, local, State, and Federal agencies were contacted, MRF's were inspected, and a literature search was performed.

It was determined that sanitation workers have an injury rate that is seven times greater than the average for all other industries combined.[1] The high injury rate for sanitation workers apparently is the result of: (1) the skill of the workers (usually drawn from the most unskilled portion of the workforce); (2) inadequate training, supervision, and education; and (3) low morale.[2] Another factor contributing to the excessive injury rate is the nature of the work (requires lifting, carrying, interface with equipment, and exposure to hazardous materials).

From the site visits that were conducted, it is apparent that handpickers at MRF's also fall into the above characterization. The above-mentioned problems, coupled with relatively low pay and poor working conditions, lead to a high turnover rate and high absenteeism at MRF's.

The following discussion focuses on the occupational health risks associated with handpicking at MRF's with a brief discussion on the overall process. In particular, the physical and biological hazards are emphasized and various controls to mitigate the problems are discussed. The applicable Occupational Safety and Health Administration (OSHA) standards are also mentioned.

6.2 PROCESS DESCRIPTION

There are two basic types of MRF's in the United States: (1) those which separate recyclable materials from MSW which has undergone no presorting and (2) those which separate "commingled" recyclables into their component materials. Commingled recyclables are metals, glass, plastics, and paper materials that have been placed in a common container and collected separately from other MSW.

At MRF's that process unsorted MSW, the MSW arrives at the facility via trucks and is dumped onto a tipping floor. At some facilities, handpickers remove cardboard, automobile batteries, tree limbs, and other large objects while the waste is still on the tipping floor. A front-end loader is then used to transfer the waste onto a conveyor belt. The conveyor belt then transports the waste to the various separation processes (e.g., screens, air classifiers, magnets, density separators, handpicking stations) to remove the recyclable materials. At some facilities, mechanical processes provide most of the separation, and handpickers are only needed to separate plastic and cardboard from the conveyor. At other facilities, most of the separation is done manually and handpickers remove glass, aluminum, plastics, paper, and other materials from MSW on the conveyor.[3-5] Further details of the process as observed at two facilities are included in Sections 4.1 and 4.2 of this report.

At MRF's that separate commingled materials, the materials arrive via truck and are deposited on a tipping floor or in a pit. The materials are then transferred to a conveyor by a front-end loader or a crane. Similar mechanical and manual methods are used for separating commingled materials as for separating unsorted MSW. The major difference is that only certain types of recyclable materials are collected and delivered to the facility; handling and processing waste containing nonrecoverable materials normally present in MSW is virtually eliminated. A description of two facilities where commingled recyclables were manually separated are contained in Sections 3.3.1 and 3.4.1 of this report.

6.3 OCCUPATIONAL HAZARDS

A variety of manifestations can result due to the physical hazards associated with the handling of MSW. Two of the most common physical hazards associated with handling MSW are back strain and injuries to the hands and fingers which account for 28 and 25 percent of the total injuries to sanitation workers, respectively.[2] The hand and finger injuries are usually manifested as abrasions, puncture wounds, lacerations, and callus formation. Studies of sanitation workers in Cincinnati and San Francisco indicated a high prevalence of abrasions, contusions, sprains, strains, and calluses.[6,7] These investigations also noted a high incidence of eye injury for sanitation workers.

A number of different physical hazards are present at MRF's that can result in these types of injuries. Probably the most pervasive of these physical hazards are sharp objects. Municipal wastes such as glass and metal can cause severe lacerations if not handled properly. Discarded television picture tubes and fluorescent light bulbs which end up in MSW pose an explosion hazard to handpickers. If these objects are broken during handling, the tube or bulb could explode projecting pieces of glass into the face of the handler. Another physical hazard that could potentially affect handpickers is the speed of the conveyor belt. If the conveyor belt is operated at high speeds, the rapid hand motions required to remove objects from the belt could result in carpal tunnel syndrome. This condition is characterized by inflammation of the area in the wrist through which the nerves, tendons, and arteries pass.

Handpickers on the tipping floor are at risk to developing back strain due to the lifting of large, heavy objects. Furthermore, equipment such as front-end or back-end loaders may operate at high speeds on the tipping floor, and there is a risk of handpickers being run into by this equipment.

Also of occupational concerns at MRF's is the generation of large quantities of dust from the physical separation of the waste stream. This dust can cause irritation of the nasal and bronchial passages and reduce visibility in the workplace. It was evident at the three facilities visited that dust was present in substantial concentrations in the tipping floor area. At one of the facilities, a high concentration of dust was present throughout the plant.

Workers who handle MSW are also exposed to a number of biological hazards. Both bacterial and viral agents that can cause disease in humans are known to be present in MSW.[8] Facial tissues, dog and cat excrement, spoiled foods, and soiled disposable diapers all can contain high levels of microorganisms. In addition to microbes in the waste itself, investigators have also detected microorganisms in the air of MRF's.[8] Although pathogenic microorganisms have been identified in both solid waste and in the air at MRF's, no adverse effects have been reported in individuals exposed to them. It is possible that the diseases caused by these organisms are not contracted in exposed individuals because the concentration of the pathogens are not high enough to cause infection. But the possibility of infection from air and wasteborne pathogens still exists for handpickers.

Although the risk posed by biological agents appears low, there are three possible infections that warrant special consideration. Hepatitis B virus and human immunodeficiency virus (HIV) are pathogenic viruses which can infect an individual via contaminated blood, while *Clostridium tetani* (that causes tetanus) is a bacteria that infects cuts and wounds. It is known that the hepatitis B virus can be viable for up to 1 week on environmental surfaces.[9] Handpickers could be exposed to the hepatitis B virus via contaminated hypodermic needles present in the waste. An operator of a MRF said he has seen hypodermic needles in the waste stream at his facility. The HIV is the viral agent responsible for the development of acquired immune deficiency syndrome (AIDS) which is also contractible via hypodermic needles containing infected blood. The risk of contracting AIDS from needles found in MSW is virtually nonexistent since HIV is very fragile under environmental conditions and should not survive in the MRF waste. Tetanus is of concern because it is caused by an opportunistic microorganism that excretes a toxin that may cause paralysis and death in humans. Because handpickers are more likely to have cuts and abrasions, they are also more susceptible to contracting tetanus.

In addition to physical and biological hazards, there are some chemical hazards associated with handpicking at MRF's. Exposure to chemicals is possible through items such as batteries, paints, solvents, and pesticides, which households may dispose of with other household wastes. By handling these items, workers can be exposed to lead, acids. chlorinated hydrocarbons, and other potentially toxic compounds.

Various health effects can result from either acute (short-term) or chronic (several years to lifetime) exposures to chemicals. Effects of acute exposures would be more readily apparent. For example, direct dermal (skin) contact with acids could cause burns. Chloracne, a skin condition, could be caused by exposure to chlorinated hydrocarbons. The probability of cancer or other effects from chronic exposures cannot be estimated without knowledge of the concentrations of each chemical to which workers would be exposed over a long time period. Information of this type has not been collected for MSW handpickers. However, in most cases, exposures are more likely to be short term in nature because: (1) exposures would depend on what chemicals are present in a particular batch of MSW, which will vary from one load to the next, and (2) since there is a high turnover rate in handpickers, most would not be employed in this occupation and exposed to chemicals in MSW over a long (multi-year) period.

6.4 TECHNIQUES TO REDUCE OCCUPATIONAL HEALTH HAZARDS

Handpicking of MSW at MRF's can have a relatively large amount of hazard associated with it. The use of personal protective equipment, engineering controls, proper work practices, and adequate training can greatly reduce occupational risks associated with handpicking at MRF's.

Personal protective equipment is very effective in minimizing occupational hazards. Since the hands and eyes of handpickers are most susceptible to injury, adequate safety glasses and gloves should be worn. The National Institute of Occupational Safety and Health (NIOSH) recommends safety glasses with side shields, canvas gauntlet gloves, and full-body coveralls for sanitation workers.[1] The canvas gauntlet gloves have suede or leather on the palms and fingertips and across the knuckles. Since cloth and latex gloves do not protect against punctures, and rubber gloves do not allow the hand to breathe, the use of these types of gloves is not advisable. Proper foot protection, especially for handpicking on the tipping floor, should be worn. Steel-toed safety shoes would be appropriate for handpickers. Dust masks should also be worn to reduce exposure to PM.

There are a couple of process changes that can be enacted to provide a safer working environment. At one of the facilities visited, the conveyor belt carrying the MSW was operating at a very fast pace. Such operating conditions are conducive to the development of carpal tunnel syndrome. By decreasing the speed of the belt, this type of adverse effect can be minimized. The use of adequate ventilation can remove particulates and airborne microorganisms from the breathing zone of the workers. By enclosing the handpicking area and using exhaust fans, which was seen at two of the facilities visited, exposure to air contaminants can be reduced. Another important engineering aspect to consider is warning lights and signals on machinery operated inside the facilities, especially the back-end loader. All machinery should be equipped with these safety devices in order to prevent collisions between the vehicles and the workers. And, finally, it is important to position the magnetic separation of metals before any handpicking stations. It was observed at one of the facilities that the handpickers were placed before the magnetic separation process. By positioning the workers after the magnets, the likelihood of cuts and wounds due to sharp metal objects can be drastically reduced.

Other important aspects to consider with handpicking operations are work practices and personal hygiene. For sanitation workers, NIOSH strongly suggests the following practices: (1) wash before eating during the workday, (2) wash before leaving work, and (3) bathe daily for protection against infection and skin diseases.[1] The National Institute of Occupational Safety and Health also recommends that the employer be responsible for the cleaning of work clothes to prevent contaminants from being taken into the home. These practices are essential to preventing infection, especially if the employee has open wounds and cuts.

An integral part of any safety program is the implementation of an employee training program. Employees should be made aware of the types of hazards that will be encountered and proper ways for handling and lifting municipal wastes. These types of programs can reduce employee turnover and, more importantly, reduce work-related injuries. It is important that the safety training be an ongoing process. Safety meetings discussing the various hazards and problems associated with the work should be conducted at least monthly. Mr. Roy Caplan, of the Milwaukee Department of Public Health, stated that the department's injury pay dropped almost by one-half a year after they implemented biweekly safety meetings for sanitation workers.[10] Therefore, continuing safety training reduces both worker injury rates and the costs that result from the lost time and medical bills.

The overall safety program for municipal waste handpickers should include an immunization program. Vaccination for hepatitis B virus and tetanus could be administered or proof of such immunization could be requested prior to the start of employment. By supplying preemployment vaccinations, infection from these two agents can be eliminated.

6.5 APPLICABLE HEALTH AND SAFETY REGULATIONS

The Occupational Safety and Health Administration promulgates standards in order to protect employees against hazards in the workplace. Section 5 (a)(1) of the Occupational Safety and Health Act of 1970 states (in the General Duty Clause), "each employer shall furnish to each of his employees employment and a place of employment which are free from recognized hazards that are causing or likely to cause death or serious physical harm to his employees." The Occupational Safety and Health Administration has no specific standards covering handpicking at MRF's but each employer in the industry must abide by the above General Duty Clause.

Although no industry-specific regulations apply, there are general industry standards which may impact MRF's. One standard that MRF's would have to comply with is the nuisance dust standard. The Occupational Safety and health Administration has set a 5 and 15 mg/m^3 permissible exposure limit for respirable and total dust, respectively, while the American Conference of Governmental Industrial Hygienists (ACGIH) has recommended a threshold limit value of 10 mg/m^3 for total dust. Respirable dust has an aerodynamic diameter of 10 μm or less. The Occupational Safety and Health Administration has recently proposed standards for occupational exposure to bloodborne pathogens including the hepatitis B virus and HIV. This standard would require employers to provide required safety measures (vaccinations, personal protective equipment, and other precautions) to reduce or eliminate potential contact with blood that is potentially contaminated.

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7.0 CHARACTERIZATION OF MERCURY-CONTAINING BATTERIES AND REVIEW OF PROGRAMS FOR THEIR SEPARATION, PROCESSING, AND DISPOSAL

7.1 INTRODUCTION AND BACKGROUND

Since household batteries are thought to be a significant source of mercury in MSW, and since conventional add-on control systems at MWC's typically achieve a lower percent removal of mercury than other metals, separation of batteries prior to combustion may be a way to achieve mercury emission reductions. At least five areas in the United States have established programs to collect household batteries, and battery separation is widely practiced in Europe and Japan. However, questions have been raised about the feasibility of collecting batteries and about how collected batteries should be handled, stored, and disposed of or recycled.

This section presents a characterization of mercury-containing household batteries in MSW and a synopsis of current collection programs and available processing and disposal options for household batteries.

7.2 CHARACTERIZATION OF HOUSEHOLD BATTERIES

7.2.1 Mercury Content of Household Batteries

The mercury content of household batteries varies according to type. Table 7-1 shows the composition of six different types of household batteries. Mercury is used in most household batteries to control hydrogen gas generating reactions between the zinc electrode and other battery components. This hydrogen gas generation causes the battery to leak and reduces performance. Therefore, a thin film of mercury is applied to the zinc electrode to prevent leakage and extend the batteries' shelf life. Mercury content in these types of batteries ranges from less than 0.01 percent to about 2 percent by weight.[1] In mercuric oxide button cell

TABLE 7-1. COMPOSITION OF HOUSEHOLD BATTERY TYPES IN 1987

Battery Type (Common Name)	Positive Electrode Material	Negative Electrode Material	Electrolyte	Typical Mercury or Cadmium Weight Per Cell(%), 1987[a]
Alkaline	Manganese Dioxide	Zinc	Alkaline Solution (Potassium Hydroxide)	Mercury Less than 1%[b]
Carbon Zinc	Manganese Dioxide	Zinc	Ammonium Chloride and/or Zinc Chloride	Mercury Less than 0.01%
Mercury	Mercuric Oxide	Zinc	Alkaline Solution (Potassium Hydroxide or Sodium Hydroxide)	Mercury 35 - 50%
Silver	Silver Oxide	Zinc	Alkaline Solution (Potassium Hydroxide or Sodium Hydroxide)	Mercury Approximately 1%
Zinc Air	Oxygen taken from the air	Zinc	Alkaline Solution (Potassium Hydroxide)	Mercury Approximately 2%
Nickel Cadmium	Nickel Oxide	Cadmium	Alkaline Solution (Potassium Hydroxide or Sodium Hydroxide)	Cadmium 17%

Source: National Electrical Manufacturers Association, 1987.

[a] The battery manufacturing industry plans to reduce mercury content of all types of household batteries except mercuric oxide batteries to 0.025 percent or less by 1993.

[b] In 1990, alkaline batteries typically contain 0.025 to 0.05 percent mercury.[2]

batteries, such as those used in hearing aids, the positive electrode is made of mercury. These batteries contain 35 to 50 percent mercury,[1] by far the largest weight-percent of mercury.

Over the past several years, the manufacturers of batteries have reduced the mercury content of most household batteries. Alkaline batteries, for example, contained about 1.0 to 1.5 percent mercury in 1984; a typical alkaline battery in 1990 contains only 0.025 to 0.05 percent. This is over a 95-percent reduction and is the result of a voluntary commitment on the part of battery manufacturers to reduce the mercury content of all but mercuric oxide batteries to 0.025 weight-percent or less by 1993. This is the same level proposed by the European Community Directive to take effect in 1993. It reflects the minimum mercury content needed to maintain battery efficiency. Battery manufacturers have said that, while they are continually researching alternative methods for controlling the behavior of zinc electrodes, they cannot currently reduce the mercury content of these batteries below 0.025 percent without significantly reducing battery performance.[2]

The mercury content of mercuric oxide batteries, which are used in small appliances and hearing aids, is not expected to decrease in the near future. Substitutes, such as zinc-air cells, are being marketed as a replacement for mercuric oxide button cells in some applications. While zinc-air cells are expected to increase their market share for use in hearing aids, overall hearing aid sales are expected to increase. Industry projections indicate that the net effect will be that the actual amount of mercury consumed as mercuric oxide button cell batteries will remain relatively constant over the next few years.[2]

Two types of household batteries, lithium and nickel-cadmium, contain no mercury. Manufacturers of lithium batteries state that each battery contains about 1 gram (g) of lithium, and that this amount does not constitute a problem for MWC's.[2] However, one battery recycling facility reports that lithium batteries, which are reactive, are sent to a separate facility for "deactivation" before they are landfilled.[3]

7.2.2 Consumption Estimates

Annual consumption of household batteries has been estimated on a per capita and per household basis. The National Electrical Manufacturers Association (NEMA) estimates battery consumption in the United States at

1 lb, or about eight batteries, per person per year.[1] Marketing studies by Duracell project that for the year 1990, the average family will purchase about 32 batteries.[1]

Figure 7-1 shows NEMA's figures for United States mercury consumption in batteries for 1983-1990. The total mercury consumed in all types of household batteries produced in the United States is reported by NEMA to be 225 tons in 1988. This is about 50 percent of all mercury consumed in the U. S. Projections for 1989 are 131 tons and for 1990 are down to 62 tons. This drop in mercury consumption is due to the industry trend towards 0.025 percent mercury content in all but mercuric oxide batteries. These tonnages do not include imported batteries, but imports are expected to add less than 10 percent to the total tonnages of mercury in household batteries.

Estimates by NEMA of the national consumption of mercury in mercuric oxide batteries are shown in Table 7-2. In 1988, consumer use of mercuric oxide batteries accounted for 46.8 tpy of mercury consumption. This was about 27 percent of all mercuric oxide battery related mercury consumption in the United States. The remaining mercuric oxide battery consumption is attributed to commercial/industrial and military uses. Mercuric oxide batteries in medical and hospital applications and miscellaneous industrial applications account for 42.7 tpy. These batteries come in many different shapes and sizes, and do not look like consumer button cell batteries. Military applications account for another 83.1 tons of mercury consumption, for a total of 172.6 tons. The fate of these batteries is not clear. For example, some MWC's do not accept hospital wastes, while other facilities do accept hospital waste if the hospitals are located in the communities that they serve. Also, some military installations have MWC's, but it is unclear whether batteries used in military applications are combusted in these MWC's.

Because the amount of mercury used for consumer mercuric oxide batteries is expected to remain relatively constant while the amount used in other batteries is expected to decrease over the next few years, consumer mercuric oxide batteries should account for a greater proportion of mercury from household batteries. If it is assumed that mercury in all

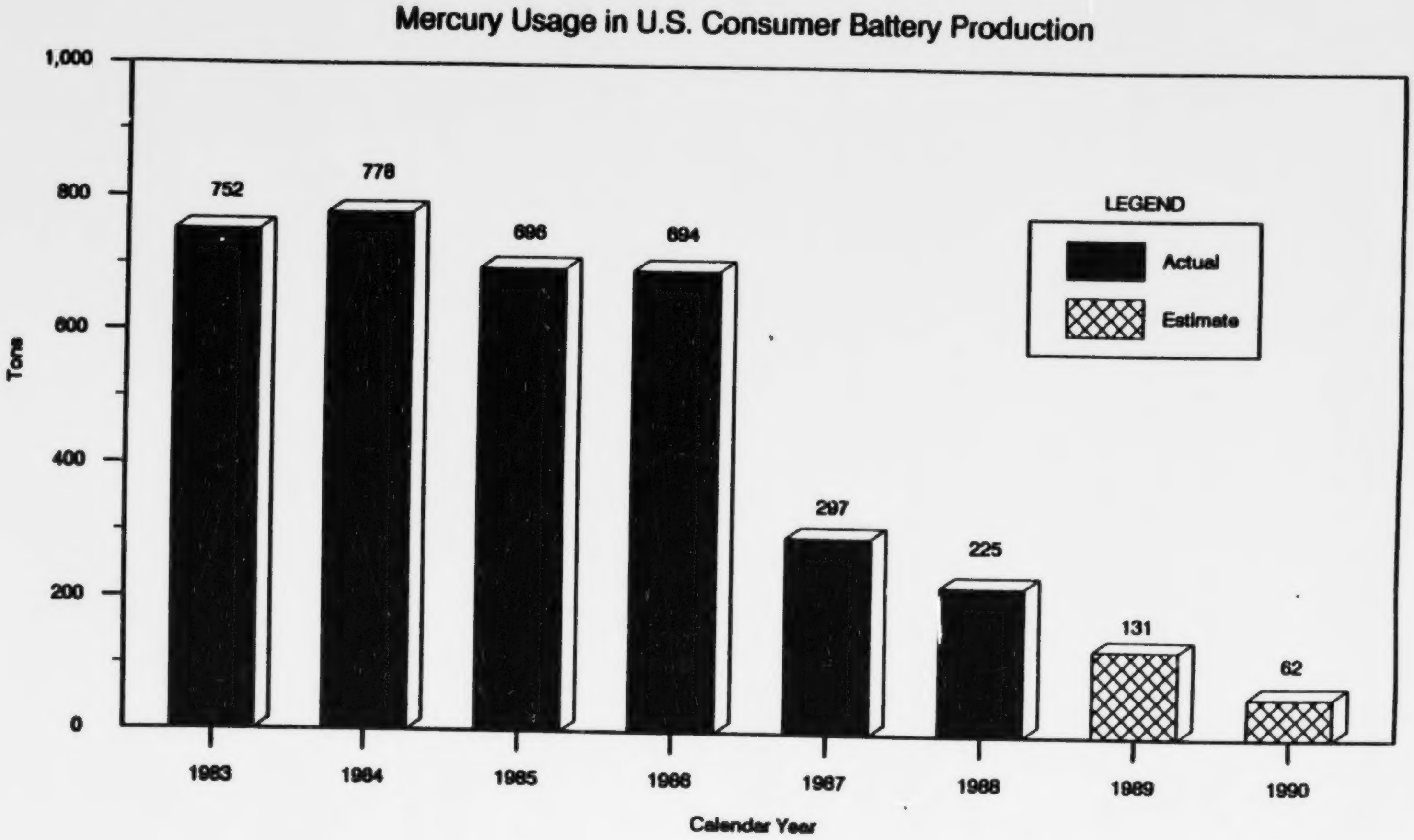

Figure 7-1. The Actual and Predicted Amount of Mercury used in U.S. Household Battery Production

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TABLE 7-2. 1988 U.S. PRODUCTION AND CONSUMPTION OF MERCURY IN MERCURIC OXIDE BATTERIES

Production

• Number of Manufacturers Producing in U.S.	3
• Short Tons of Mercury Used in Production	116.4
• Short Tons of Mercury Exported	5.9

Consumption

• Number of Manufacturers Selling in U. S.	6
• Short Tons of Mercury Imported	62.1
• Short Tons of Mercury Used in Consumption	172.6
• Short Tons of Mercury Used in:	
•• consumer applications	46.8
•• medical/hospital applications	24.7
•• other industrial applications	18.0
•• military applications*	83.1

*includes use by U. S. miliary and NATO overseas

Source: National Electrical Manufacturers Association consumer batteries in 1990 is 62 to 70 tons (Figure 7-1 shows 62 tons produced in the United States), and that about 46 tons are used in mercuric oxide consumer batteries (from Table 7-2), then about 65 to 75 percent of the total mercury in household batteries can be attributed to mercuric oxide button cell batteries.

There is a lack of information on the percent of total mercury in MSW that is attributable to household batteries. Other sources of mercury in MSW include thermometers, thermostats, electrical circuitry, switches and relays, paints, electrical lighting, and other miscellaneous items in residential or commercial/institutional waste. A 1988 U. S. Bureau of Mines report shows that the total amount of mercury use in battery production declined by more than 55 percent from 1984 to 1988.[4] A Swedish report from 1984 states that mercury emissions for MWC's could be reduced by 70 percent through battery separation.[5] However, given the rapid decline in mercury use in batteries over the last 4 years, this estimate is likely to be out of date.

7.3 CURRENT BATTERY COLLECTION PROGRAMS

There are currently at least five battery collection programs in place in the United States. They vary in structure and organization from local efforts in small towns or suburbs, to State or regional efforts. In Hennepin County, Minnesota, pilot programs for collection of household batteries were undertaken for about 6 months in two suburbs. A Missouri program which covers 23 counties, collects only button cell batteries. New Hampshire and Vermont cooperate in a mixed household battery collection program which has been in place for over 2 years and involves 26 towns and surrounding rural areas.[1] Warren County, New Jersey, has a pilot collection program where residents can deposit batteries at select stores.[6] The City of Bellingham, Washington, in conjunction with a local MWC operator, has been conducting a program for 2 years which collects mixed household batteries from over 40 retail stores.[7]

Generally, the programs are not heavily funded, and often rely on volunteer workers. The most significant cost incurred by most collection programs is landfill fees for disposing of collected batteries. When handed separately, mercury oxide and silver oxide batteries are often taken to a processor for recycling. Recycling is not presently possible for other types of mercury-containing household batteries, and these batteries are commonly landfilled. A concern with storage has been exposure to high indoor ambient mercury levels in areas where batteries are stored.

7.3.1 Collection Procedures

Reports from the five battery collection programs cited above indicate that battery collection may occur either at drop-off centers in retail stores where batteries are sold, or at the curbside in conjunction with household garbage collection.[1,2] Most programs included a drop-off component.

For retail store collection, some projects have relied on specially designed cardboard collection boxes, while others have used plastic or galvanized buckets. In one case, participating camera and jewelry stores collect only mercury and silver oxide button cell batteries exclusively and sell them to a battery recycler. Other programs collect mixed batteries at retail stores and other locations. The button cell batteries can be identified by the serial number on the battery casing and can be separated by hand and sent to a battery recycler. Other types of batteries are usually stored or landfilled.

Retail store drop-off programs have been administered in a variety of ways. Some mixed battery collection programs have been organized by county or regional waste disposal authorities who have enlisted retailers to participate, publicized the programs, organized collection of batteries from the retailers, and been responsible for storage and disposal. In the Missouri case, a nonprofit organization contacted retail stores selling button cell batteries and a company that recovers mercury from button cell batteries, facilitated private collection efforts, and also publicized the programs. Many retailers have been cooperative, while others are unwilling to participate.

Newspaper and radio advertisements, direct mailings, flyers and posters in stores and in senior citizen centers (where people are likely to use mercury oxide hearing aid batteries) have been tried to publicize programs. Most programs rely in part on volunteer groups, such as Optimist Clubs, Boy Scouts, and Retired Senior Volunteer Programs for monitoring collection sites, delivering batteries from collection sites to central locations, and/or separating of various types of batteries from the mixture collected.

A pilot curbside collection program was implemented in the community of New Hope in Hennepin County, Minnesota. Residents were sent ziplock bags and instructions to place batteries in the bags at the curbside with other recyclables on two specified days over a several-month period.[1]

In Europe, at least 10 countries (Austria, Belgium, Denmark, France, Italy, The Netherlands, Norway, Sweden, Switzerland, and West Germany) and Japan have battery collection programs. Most countries collect mixed batteries. In Belgium and France, however, only button cells batteries are collected. Batteries are collected at retail stores and drop-off locations in most cases. Three countries, Austria, Denmark, and Switzerland, are planning to implement deposit or rebate programs to encourage recovery. In Sweden and Japan, batteries are collected at curbside in addition to drop-off and retail locations; in Japan, this is reported to be the most popular collection method.[8]

Several European countries are planning additional regulatory measures for household batteries. Most of these measures will be implemented in 1990. Available information on regulations for household batteries in European countries is shown in Table 7-3.[9]

7.3.2 Collection Efficiency

Over approximately 2 years, 7 tons of mixed batteries were collected in the New Hampshire/Vermont program, which serves about 72,000 people. In Hennepin County, Minnesota, a total of just over 1 ton was collected between February and November 1989 from a population of about 40,000. Of the county's two pilot programs, the curbside collection effort brought in more batteries than did the retail location effort.[10]

Estimated battery recovery rates are 10 percent for New Hampshire/Vermont, and about 3 percent for Hennepin County.[1,10] These rates are calculated using collection data and NEMA projections of per capita battery consumption. Data are not available for other programs. New Hampshire/Vermont's rate of 10 percent is considered a good rate of removal in light of the low budgets and fairly low profile usually allotted to battery collection.[2] Program coordinators have stated that up to 20 or 25 percent removal might be achieved with aggressive publicity or if curbside collection was done on a frequent, regular basis.[2] However, collection rates above 10 percent have not been demonstrated in the United States.

TABLE 7-3. REGULATORY MEASURES FOR HOUSEHOLD BATTERIES IMPLEMENTED BY EUROPEAN COUNTRIES IN 1990

Country	Battery Type	Regulatory Action
Denmark	Nickel-cadmium	10% rebate
Norway	Mercury or cadmium	Tax for >0.025% nickel or cadmium content
Sweden (currently)	Nickel-cadmium, alkaline, button cell	Environmental fee for >0.025% mercury or cadmium content
Sweden (planned)	Nickel-cadmium, alkaline, button cell	Ban on >0.025% mercury or cadmium content
Switzerland	Not specified	Deposit
West Germany	Mercury oxide, Nickel-cadmium, Alkaline	Labeling required for >0.1% mercury content
Austria	Not specified	Labeling and deposits

Available information on recovery rates in Europe and Japan are presented in Table 7-4.[11] Recovery rates have been higher than in the United States.

7.3.3 Sorting, Storage, and Disposal

Batteries collected by the U. S. programs are disposed of either through recycling facilities where mercury and silver are recovered, or they are landfilled or stored. Currently, mercury oxide and silver oxide batteries can be recycled, and two companies located in the U.S. are available for reclaiming metals from nickel-cadmium batteries. However, there are no plants recycling other types of household batteries, so these are stored or landfilled. Usually, collected mixed household batteries are taken to hazardous waste landfills. Reported charges are $350 per 55-gallon drum for the New Hampshire/Vermont program (one 55-gallon drum weighs about 650 lb), and $500 per ton for the Hennepin County pilot program. The New Hampshire/Vermont program has successfully offset landfill fees for batteries with tipping fees from the local MWC. In Hennepin County, the landfill fee was considered prohibitive. Consequently, their batteries remain in storage. A representative for the Warren County, New Jersey, program said they hand sort the mercury oxide button cell batteries and plan to send them to a recycler, but are presently storing the remaining batteries in plastic buckets and have yet to identify a place of disposal. In Bellingham, Washington, the batteries have been stored in plastic buckets outside of the local MWC for over 2 years. A representative of the program said that the batteries are being stored pending market development.[7]

Most batteries collected in Europe are also stored or landfilled. There are facilities for recovery of nickel and cadmium from nickel-cadmium batteries in Europe (at one plant in France and one plant in Sweden), and there are no mercury recovery facilities. Silver is recovered from silver oxide button cell batteries. Most separated batteries containing mercury or cadmium are put in long-term storage in underground salt domes in West Germany. Others are stored or landfilled at various locations. Most batteries collected in Japan are put in long-term storage, but some are sent to the Clean Japan Center's Itomuka demonstration plant for metals recycling.[12]

TABLE 7-4. ESTIMATED RECOVERY RATE OF HOUSEHOLD BATTERIES IN EUROPE AND JAPAN

Country	Battery Type	Recovery Rate (%)
Denmark	Alkaline and zinc-carbon	25%
	Button cell	80%
Sweden	All types	60%
Switzerland	All types	30%
Japan	All types	20% Average 40-50% Maximum

7.3.4 Safety Considerations

Storage of collected batteries has caused concern over possible exposure to mercury vapors as well as possible ingestion of button cell batteries. In Hennepin County, elevated ambient mercury levels have been detected when battery storage containers were opened. Mercury was detected at levels of up to 0.5 mg/m^3 in containers which had contained alkaline batteries for 3 months.[8] In Denmark, mercury has been measured at levels from 0.015 to 2.5 micrograms per cubic meter ($\mu g/m^3$) in various battery storage areas, and from 0.75 to 0.92 $\mu g/m^3$ above manual sorting tables. A level of 74.5 $\mu g/m^3$ was measured in a closed container of mixed batteries stored for 4 months.[12]

The OSHA permissible exposure limit (PEL) for mercury vapor is an 8-hour time weighted average (TWA) of 0.05 mg/m^3, or 50 $\mu g/m^3$. Inorganic mercury and mercury vapor also have a "skin designation," which means that they can be absorbed through the skin (54 FR 2942, January 19, 1989). Exposure to mercury and mercury vapors could be of concern to volunteer and retail store workers who handle or work near collected batteries.

Improperly stored batteries also pose a potential risk of explosion. If batteries are stored in a container such that incompletely discharged batteries make electrical contact, some batteries can become overcharged. These overcharged batteries generate heat and pressure which ruptures the battery seal, thereby liberating hydrogen gas which is highly explosive. At least one such incident has been reported in which a barrel of batteries being unloaded from a truck exploded and injured a worker.[13]

Public and professional concern has also been expressed over the increased likelihood of button cell battery ingestion if batteries are improperly handled or stored in homes or during collection.[14,5] The National Capital Poison Center reports over 1,340 cases of button cell battery ingestion from 1983 to 1988, including two fatalities in small children. Injuries incurred by battery ingestion include permanent esophageal injury. In addition, perforation of the ear drum as well as permanent impairment of hearing have occurred following accidental battery placement in the ear by children as well as adults.[14] In light of these hazards, both the American Association of Retried Persons (AARP) and the National Capital Poison Center have expressed strong opposition to battery collection legislation proposed in the New York State Assembly. Both organizations urge that, where household batteries are collected, care must be taken to prevent their misuse. The use of slotted containers for the storage of button cell batteries in the home could help to prevent their misuse.

7.4 CURRENT RECYCLING EFFORTS

7.4.1 Mercury Oxide Battery Recycling Process

In the United States, there is currently only one metals recovery facility that recycles mercury from post-consumer household batteries. Mercury Refining Company of Latham, New York, recycles mercury oxide and silver oxide button cell batteries.

The batteries are put in a "retort" oven along with other mercury-containing items, and heated to between 1,000 and 1,200°F. Mercury vapors generated in the oven are collected in a condenser operated at 90 to 100°F. The collected mercury goes through two more purification steps, and is then sold for use in dental work, fluorescent lights, thermometers, and batteries. Other liquids are sent to wastewater treatment processes or hazardous waste incinerators. Solids, including battery casings, are sent to a hazardous waste landfill, although they usually pass the EP toxicity test. When a shipment contains mainly silver oxide batteries, the solids are further processed to concentrate the silver, which is sold to another refiner for further purification. In 1989, Mercury Refining Company recycled over 28,000 lb of button cell batteries. They currently receive button cell batteries from seven communities.[2]

Mercury Refining Company will also accept other types of batteries from communities. Only the button cell batteries are recycled on site. These are screened from other batteries by size. Lithium batteries, which are reactive, are sent to another facility for "deactivation" and then landfilled. Carbon-zinc and alkaline batteries are put in a hazardous waste landfill. Payments to Mercury Refining or to the community depend on the mixture of batteries. Mercury Refining Company can pay for mercury oxide or silver oxide button cell batteries. However, communities pay Mercury Refining to take mixed household batteries.

Some mercury is emitted during the battery recycling process. The Mercury Refining Company's permits allow 48 lb/yr total mercury emissions from the facility. The OSHA regulations, training, and monitoring programs are followed to protect worker health and safety.

In Europe, silver oxide batteries can be recycled to recover silver, but there are no plants recovering mercury from batteries.

7.4.2 Development of Processes to Recycle Other Types of Batteries

Currently, there are no commercial facilities in the United States or Europe to recover metals from alkaline batteries and most other types of household batteries.

One company in the United States, Inmetco of Ellwood City, Pennsylvania, recovers nickel from industrial nickel-cadmium batteries and would also recycle household nickel-cadmium batteries if they were separated from other batteries. Another company, NIFE, Inc., which is based in Sweden but has a subsidiary in Greenville, North Carolina, accepts industrial and household nickel-cadmium batteries for shipment to their recycling facility in Sweden. Both Inmetco and NIFE charge a fee for accepting the batteries.[16]

Some research is being done in Europe, Japan, and the United States to develop battery recycling processes and test them on laboratory and pilot scales. Commercial facilities may be built in the future. Some examples of processes being investigated or developed are described below.

Recytec, Inc., is developing a process for recovering metals from mixed household batteries. They are operating a 100 tpy pilot-scale process in Switzerland. They have also acquired a site and completed design for a 500 tpy commercial facility in Switzerland and are currently involved in equipment sourcing and project financing activities. The company has offices in Maryland and New Jersey and hopes to market the process in the United States.[2]

The Recytec process uses mixed household batteries. No presorting would be required. An initial thermal treatment step volatilizes mercury and some of the cadmium. The collected condensate is mainly mercury, and can be sold in Europe. The battery solids are then processed by shredding and magnetic separation in preparation for the electrowinning steps. Flouroboric acid, which is used in the metal plating industry, is used in electrolytic treatment steps to recover metals from the battery solids mixture. Metals recovered include manganese, zinc, iron, cadmium, copper, silver, gold, and nickel. High purities (e.g., 99 percent) are achieved for the individual metals or compounds recovered. Most of these metals can be sold. About 95 percent of the total inputs are recovered, leaving only 5 percent residual waste.[2]

Since a full-scale facility has not been built, actual economic data are not available, however representatives said costs to recycle batteries would probably be similar to fees charged by hazardous waste landfills.

In an effort to recover some of the raw materials lost with battery disposal, the Clean Japan Center began a joint venture with State and private funding.[17] The project includes collection of mixed battery types, sorting, and recovery of mercury, zinc and iron at a pilot facility. The recycling process consists of the following steps: a combination of mechanical and hand sorting by size, then by metal content; mechanical dismantling of batteries and separation of iron jackets; heating in a rotary furnace to between 1,200°F and 1,500°F to vaporize mercury; magnetic separation of iron and zinc; recovery by condensation of vaporized mercury; further treatment of gases and recovery of chloride and residual mercury; and, finally, wastewater treatment. Recovered mercury is further refined to a purity of 99.99 percent.[17]

The facility processes approximately 20 tpd under optimal conditions. The recovery ratios (weight of recovered material/weight of waste batteries) for reusable materials are 0.05 percent for mercury, 14 percent for iron, and 54 percent for zinc residue.[17] Facility emissions are reportedly within the standards of Japan's Air Pollution Prevention Act, and ambient mercury levels are below the World Health Organization guideline of 0.015 milligrams per normal cubic meter (mg/Nm^3).[17]

Although fees were charged for acceptance of batteries and recovered materials were sold, the facility failed to cover costs of operation during its 2-year pilot operation. A report from the Clean Japan Center states that profitable operation is expected once supplies of feed materials and market prices stabilize.

Sumitomo Industries, Ltd. of Japan has researched a process for recovering metals from mixed household batteries. Sumitomo has constructed a 100 Kg/hour pilot demonstration plant in Japan, but currently does not have a commercial operation. The Sumitomo process uses a pyrometallurgical concept to recover saleable mercury, zinc, and ferro-manganese alloy from mixed, unprocessed dry cell batteries.

A treatment fee for accepting and recycling the batteries or other source of revenue will be needed to operate the plant since the revenue from the sale of recovered metals is not expected to cover costs. However, since a full-scale facility has not been constructed, actual economic data are not available.[18]

There are no pilot plants in the United States; however, some research on potential battery recovery processes is beginning. For example, Bronx 2000, a nonprofit economic development organization, is conducting a 1-year feasibility study in 1990. The study objectives are to characterize batteries, identify materials that may have value if reclaimed from batteries, and identify potential reclamation processes. Bronx 2000 is also working with Polaroid Corporation to recycle their zinc-carbon batteries in-house, and has completed a lab-scale demonstration.[2]

7.5 SUMMARY

Total usage of mercury in household batteries has declined rapidly in the past few years, and the battery manufacturing industry plans to further reduce the mercury content of all but mercuric oxide batteries to 0.025 percent by 1993. At this level of production, the mercury content of all but mercuric oxide batteries would be reduced by over 97 percent as compared to levels in 1984. It is estimated that mercuric oxide batteries are now the major source of mercury in household batteries due to the recent decline in the mercury content of alkaline batteries.

Collection efforts in the United States are minimal and consist primarily of low budget, volunteer-oriented projects. The highest reported collection rate is roughly 10 percent. Battery collection projects are better developed in Europe and Japan, where the collection efficiency is typically about 20 to 30 percent.

Disposal of collected batteries is problematic. There is only one facility in the United States which recycles mercuric oxide and silver oxide button cell batteries. This may be a deterrent to further household battery collection efforts. The majority of collected household batteries are either stored or disposed of in hazardous landfills, because there are currently no commercial recovery facilities for these types of batteries. With the exception of the one U. S. facility that recycles button cell batteries, no facilities in the United States or Europe have been identified which recover mercury from alkaline or other types of household batteries. The cost of landfilling is sometimes prohibitive to battery separation.

Collection, storage, and sorting of household batteries can also expose workers to health hazards. Elevated ambient levels of mercury have been measured in association with battery collection efforts in the United States and in Europe. Public and professional concern has been expressed over the possible increased likelihood that children and elderly people will ingest button cell batteries collected for recycling.

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APPENDIX A

MATERIALS SEPARATION REPORTING AND DOCUMENTATION METHODOLOGY

1. Introduction

The following four forms (A, B, C, and C1) are sample forms which may be used by MWC owners or operators in tracking and reporting amounts of materials separated from MSW prior to combustion. The forms may serve as useful examples of the types of information and documentation the Agency considers important in verifying overall levels of materials separation.

2. Description of Use of Example Forms

2.1 Form A. Form A is the Annual Materials Separation Tonnage Summary Form. Form A would be prepared annually by each MWC operator to report all on-site and off-site materials separation claimed by that MWC. This form summarizes total weight (in metric tons or Mg) of all materials separated. Weights of all materials separated on-site at the MWC, off-site through county or municipal collection programs, or off-site by another party (e.g., private non-profit groups or commercial businesses) are added together and then entered on this form. The total weight summarized on Form A is used as the basis for determining the overall percent separation level. The weights (Mg/year) summarized on Form A are derived from weights (Mg/year) submitted to the MWC operator by individual parties on either Form B or Form C.

2.2 Form B. Form B is the Off-Site Materials Separation Reporting Form for Materials Measured on a Weight Basis. Form B would be used by individual parties separating materials off-site to report weights of separated materials documented by that party. Each individual community, non-profit group, or commercial business in the MWC service area would submit a separate Form B to the MWC operator in order to apply the weights of those materials to the overall percent separation level. Proper documentation should be attached to Form B for all of the weights of materials reported on Form B.

2.2.1 Documentation to Accompany Form B. Proper documentation for Form B includes: (1) actual weight receipts from the business or market purchasing/accepting the separated material; (2) accounting summarizations of multiple weight receipts; (3) letters from the business or market stating the amount of separated materials purchased/accepted from parties within the MWC service area; or (4) letters from the generator (e.g., private community group, business generating a separated recoverable material) stating the amount separated and the business or market to which the material was delivered. The summarizations of multiple weight receipts, letters from markets and letters from generators are means of submitting documentation in a simplified, condensed form. For example, it may be less burdensome for a municipality to submit one accounting summarization sheet containing information from hundreds of weight receipts rather than submit each of the individual weight receipts. Accounting summarization sheets are considered acceptable documentation as long as they include for each material transaction the: (1) date; (2) receipt number; (3) business or market accepting the material; (4) type of material; and (5) weight of material. Signed letters from the market or from the generator should identify the provider and acceptor of the materials. The letter should also include the type(s) of material(s) and weight of each material delivered during a specified calendar period.

2.2.2 Retention of Documentation. If weight receipt accounting summarizations or letters from the generator or the business/market accepting the material are submitted, documentation pertaining to individual transactions should be retained for 2 years following submittal. The person submitting the simplified documentation should also indicate the contact person and company/location where the supporting documentation is retained. Supporting documentation should also be made available for review by the appropriate authorities.

2.3 Form C. Form C is the Tonnage Calculation Estimation Form for Separated Materials Measured on a Volume Basis. While materials that are directly weighed should be reported on Form B, Form C provides an alternative for reporting materials that are commonly measured on a volume basis. Yard waste is often measured on a volume basis (i.e., by the cubic meter or truckload) and may not be weighed on scales. Other materials may be traded at the market on a volume basis. For example, corrugated paper may be bought and sold by the bale. For each material measured on a volume basis, the volume of material separated is entered on Form C and the estimated weights are calculated by converting from volumes to metric tons (Mg) using the conversion factors provided on Form C.

2.3.1 Documentation to Accompany Form C. Documentation submitted with Form C is virtually the same as for Form B except that (1) volume receipts, (2) accounting summarizations of volume receipts, (3) letters from generators or (4) letters from businesses or markets accepting materials would state the volumes of materials separated instead of weight-based documentation.

2.3.2 Retention of Documentation. The same procedures for retaining records of individual transactions specified in paragraph 2.2.2 for Form B would also apply to Form C.

2.3.3 Form C1. Form C1, the Yard Waste Collection Log, may be used to document the volume of yard waste separated since yard waste is not usually traded in traditional markets. Form C1 documents the type of yard waste collected, the volume of the collection truck, and the date of each load of that material collected. A separate Form C1 should be filled out for each type of yard waste material (e.g., leaves, grass clippings, wood chips). The total volumes of the various yard waste materials recorded on Form C1 are used to calculate estimates of the total weights of separated yard waste materials on Form C.

2.4 Signature of Forms. Each of the forms (A, B, C, and C1) should be signed by the person submitting the form. The certification statement to be signed includes the statement that the materials claimed on the form were generated in the MWC service area and were not combusted. Form A would be verified and signed by the MWC owner or operator. Forms B or C submitted by a municipality or county would be verified and signed by the recycling coordinator, solid waste utility superintendent, or other responsible employee of that municipality or county. Forms B or C submitted by a business, community group, or other organization would be verified and signed by a responsible representative of that organization.

2.5 Summary. In summary, all materials separated on-site and off-site would be reported by the MWC owner or operator on Form A to determine the overall percent separation level. Form B and/or Form C should be submitted by individual parties performing off-site separation for all materials separated off-site that are reported on Form A. Documentation for individual materials transactions or summaries of those transactions should accompany Form B and Form C. If documentation summaries are submitted, documentation of individual transactions should be retained and these records made available for inspection by the appropriate authorities upon request. Form C1 may be submitted as documentation for yard waste collected on a volume basis and reported on Form C.

FORM A - SIDE 1

ANNUAL MATERIALS SEPARATION TONNAGE SUMMARY FORM
(To Be Completed by the MWC Operator or Co-operator)

__DIRECTIONS__: To report annual materials separation tonnage, complete Sections 1, 2, and 3 of this form and attach Forms B and/or Form C along with supporting documentation. Type all entries. Insert the total tonnage in the appropriate columns.

1. APPLICANT INFORMATION

Name of MWC ______________________________

Street Address of MWC ______________________________

City, State, Zip Code ______________________________

Contact Person ______________________________

Title ______________________________

Mailing Address ______________________________

City, State, Zip Code ______________________________

Telephone (   ) ______________________________

2. MWC CERTIFICATION

I hereby certify that the tonnage claimed below on this form represents materials generated in the MWC service area and that these materials were separated during the calendar year covered by this application through separation for recovery and that the materials claimed were not combusted.

____
Signature

______________________________ ______________________________
Title Date

FORM A - SIDE 2

3. MATERIALS SEPARATION SUMMARY TOTALS

Enter the total number of metric tons (or megagrams [Mg]) claimed for each material separated (round off to the nearest hundredth).

	On-site at MWC	Off-site	Total
Paper			
Newspaper			
Hi-Grade (Office or Computer Paper)			
Corrugated			
Other Paper			
Glass			
Glass Containers			
Other Glass			
Metal			
Aluminum Cans			
Bi-Metal Cans			
Other Nonferrous			
Ferrous Cans			
White Goods			
Other Ferrous			
Ferrous Recovered from MWC Ash		x (0.5)	
Plastic			
Plastic Containers			
Other Plastics			
Yard Waste			
Grass Clippings			
Leaves			
Wood Chips			
Other Yard Waste			
Automotive Maintenance			
Motor Oil			
Tires			
Vehicle Batteries			
Household Hazardous Waste			
Household Batteries			
TOTAL METRIC TONS SEPARATED			

FORM B -SIDE 1

THIS BOX TO BE COMPLETED BY MWC OPERATOR OR CO-OPERATOR ONLY.

___ of ___ Form B's included on Form A

OFF-SITE MATERIALS SEPARATION REPORTING FOR MATERIALS MEASURED ON A WEIGHT BASIS

(To be Completed by Each Party Performing Off-Site Separation)

DIRECTIONS: COMPLETE BOTH SIDES AND SIGN THIS FORM. TYPE ALL ENTRIES. ATTACH DOCUMENTATION TO VERIFY TONNAGE. Use this form to report documented, separated tonnage totals for any group performing off-site separation at a location other than the MWC (e.g., County/Municipal Agencies, Non-profit Organizations, Direct Sales to a Market by Individual(s), and the Business/Commercial Sector). Complete and submit one form for each agency, organization, individual, or business. Submit forms to the MWC operator (or the co-operator in cases where the municipality or county is the co-operator for materials separation). FAILURE TO COMPLETE BOTH SIDES, INCLUDING SIGNATURE, OR FAILURE TO ATTACH SUPPORTING DOCUMENTATION WILL RESULT IN THE DISALLOWANCE OF TONNAGE.

1. **INFORMATION ON PARTY REPORTING SEPARATED TONNAGE** (File a separate Form B for each agency/organization/individual/business performing off-site separation).

A. Name ______________________________

B. Mailing Address ______________________________
____

C. City, State, Zip Code ______________________________

D. Contact Person ______________________________

E. Title ______________________________

F. Telephone No. (   ) ______________________________

G. Type of Agency/Organization/Business (check one)

____ County/Municipal Agency
____ Volunteer/Non-Profit
____ Service Operation
____ Industrial (specify product) ______________________________
____ Manufacturer (specify product) ______________________________
____ Other (specify) ______________________________
____
____ Retail Operation
____ Wholesale Operation
____ Agriculture
____ Recycling Market
____ Office Building(s)
____ Waste Hauler

H. Name of MWC to Which Form B is Being Submitted ______________________________

2. **DOCUMENTATION**

For audit purposes, indicate where supplementary records are kept as well as a contact person.

Name ______________________________ Title ______________________________

Location ______________________________ Phone (   ) ______________________________

3. **PREPARER'S CERTIFICATION**

I hereby certify that the tonnage claimed below on this form represents materials generated in the MWC service area and that these materials were separated during the calendar year covered by this application and that the materials claimed were made available for recycling and not combusted. I further agree to grant the delegated authority access to those records needed to verify the information provided in connection with this reporting procedure.

____
Type Name of Individual, Recycling Coordinator, or Organization/Business Representative

____
Signature of Individual, Recycling Coordinator, or Organization/Business Representative

____
Title

____
Date

FORM B - SIDE 2

4. SEPARATED MATERIAL TOTALS (Round off to the nearest hundredth).

MATERIAL	Mg[a]	CITY, COUNTY, AND STATE WHERE GENERATED	MARKET COMPANY NAME, CITY, AND STATE ACCEPTING MATERIAL
Paper			
Newspaper			
Hi-Grade (Office or Computer Paper)			
Corrugated			
Other Paper			
Glass			
Glass Containers			
Other Glass			
Metal			
Aluminum Cans			
Bi-Metal Cans			
Other Nonferrous			
Ferrous Cans			
White Goods			
Other Ferrous			
Plastic			
Plastic Containers			
Other Plastics			
Yard Waste			
Grass Clippings			
Leaves			
Wood Chips			
Other Yard Waste			
Automotive Maintenance			
Motor Oil			
Tires			
Vehicle Batteries			
Household Hazardous Waste			
Household Batteries			
TOTAL Mg			

---

[a] Mg designates megagrams or metric tons; 1 Mg = 1.1 ton = 2,200 lbs.

FORM C - SIDE 1

THIS BOX TO BE COMPLETED BY MWC OPERATOR OR CO-OPERATOR ONLY.

__ of ___ Form C's included on Form A

TONNAGE CALCULATION ESTIMATION FORM FOR MATERIALS MEASURED ON A VOLUME BASIS

(To be Completed by Each Party Performing Off-Site Separation)

DIRECTIONS: COMPLETE BOTH SIDES AND SIGN THIS FORM. TYPE ALL ENTRIES. ATTACH FORM C1 AND/OR OTHER SUPPORTING DOCUMENTATION TO VERIFY VOLUMES SEPARATED. Use this form to report documented, separated volume totals for materials measured on a volume basis and to calculate tonnage estimates for these materials. Complete and submit one form for each agency, individual, organization, or business performing off-site separation. Submit forms to the MWC operator (or the co-operator in cases where the municipality or county is the co-operator for materials separation). FAILURE TO COMPLETE BOTH SIDES, INCLUDING SIGNATURE, OR FAILURE TO ATTACH SUPPORTING DOCUMENTATION WILL RESULT IN THE DISALLOWANCE OF TONNAGE.

1. **INFORMATION ON PARTY REPORTING ESTIMATED SEPARATED TONNAGE** (File a separate Form C for each agency/organization/business performing off-site separation).

A. Name ______________________________

B. Mailing Address ______________________________

____

C. City, State, Zip Code ______________________________

D. Contact Person ______________________________

E. Title ____________________

F. Telephone No. (   ) ____________________

G. Type of Agency/Organization/Business (check one)

___ County/Municipal Agency
___ Volunteer/Non-Profit
___ Service Operation
___ Industrial (specify product) ______________________________
___ Manufacturer (specify product) ______________________________
___ Other (specify) ______________________________
___ Retail Operation
___ Wholesale Operation
___ Agriculture
___ Recycling Market
___ Office Building(s)
___ Waste Hauler

H. Name of MWC to Which Form C is Being Submitted ______________________________

2. **DOCUMENTATION**

For audit purposes, indicate where supplementary records are kept as well as a contact person.

Name ____________________ Title ____________________

Location ____________________ Phone (   ) ____________________

3. **PREPARER'S CERTIFICATION**

I hereby certify that the tonnage estimated on this form represents materials generated in the MWC service area and that these materials were separated during the calendar year covered by this application and that the materials claimed were made available for recycling and not combusted. I further agree to grant the delegated authority access to those records needed to verify the information provided in connection with this reporting procedure.

____
Type Name of Individual, Recycling Coordinator, or Organization/ Business Representative

____
Signature of Individual, Recycling Coordinator, or Organization/ Business Representative

____
Title

____
Date

FORM C - SIDE 2

4. SEPARATED MATERIAL TOTALS (Round off to the nearest hundredth).

MATERIAL	VOLUME (m^3)		CONVERSION FACTOR (Mg^a/m^3)		Mg	CITY, COUNTY, AND STATE WHERE GENERATED	MARKET COMPANY NAME, CITY, AND STATE ACCEPTING MATERIAL
Paper							
Corrugated (uncompacted)	______	x	0.169	=	______	______	______
Corrugated (compacted)	______ (drums)[b]	x	0.301 (Mg/drum)	=	______	______	______
Glass							
Uncrushed	______	x	0.079	=	______	______	______
Manually crushed	______	x	0.138	=	______	______	______
Mechanically crushed	______ (m^3)	x	0.249 (Mg/m^3)	=	______	______	______
Metal							
Aluminum Cans (whole)	______	x	0.044	=	______	______	______
Aluminum Cans (flat)	______	x	0.148	=	______	______	______
Ferrous Cans (whole)	______	x	0.089	=	______	______	______
Ferrous Cans (flat)	______	x	0.505	=	______	______	______
White Goods	______ (m^3)	x	0.089 (Mg/m^3)	=	______	______	______
Plastic							
PET Containers	______	x	0.018	=	______	______	______
HDPE Containers (whole)	______	x	0.018	=	______	______	______
HDPE Containers (flat)	______ (m^3)	x	0.045 (Mg/m^3)	=	______	______	______
Yard Waste (from Form C1)							
Grass Clippings (uncompacted)	______	x	0.439	=	______	______	______
Grass Clippings (compacted)	______	x	0.659	=	______	______	______
Leaves (uncompacted)	______	x	0.237	=	______	______	______
Leaves (compacted)	______	x	0.593	=	______	______	______
Leaves (vacuumed)	______	x	0.409	=	______	______	______
Wood Chips	______	x	0.250	=	______	______	______
Brush	______ (m^3)	x	0.148 (Mg/m^3)	=	______	______	______
Automotive Maintenance							
Motor Oil (gallons)	______	x	0.00084 Mg/liter	=	______	______	______
Passenger Tires (# of tires)	______	x	0.009 Mg/tire	=	______	______	______
Truck Tires (# of tires)	______	x	0.041 Mg/tire	=	______	______	______
Automotive Batteries (# of batteries)	______	x	0.0150 Mg/battery	=	______	______	______
TOTAL Mg					______		

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[a] Mg designates megagrams or metric tons. 1 Mg = 1.1 tons = 2,200 lbs.

[b] Equals one 55-gallon (208 liter) drum.

FORM C1

THIS BOX TO BE COMPLETED BY MWC OPERATOR OR CO-OPERATOR ONLY.

Volume from this Form C1 reported on Form C # ____.

YARD WASTE COLLECTION LOG
MATERIALS MEASURED ON A VOLUME BASIS

(To be Completed by Each Party Performing Off-Site Separation)

DIRECTIONS: Complete separate Yard Waste Logs for each month and for each material collected, i.e., leaves, grass clippings, woodchips. Use only one column for each vehicle. For leaves, specify the method of collection, the vehicle number, and the meter (m^3) capacity of the vehicle. For other yard waste materials, specify the vehicle number and cubic meter capacity of the vehicle. All yard waste must be reported in cubic meters on Form C1. The total tonnage is estimated and reported on Form C. Also, indicate the total number of loads and cubic meters at the bottom of each column.

MONTH ____________ YEAR _______ MATERIAL ________________________

	Vehicle No. __________ Capacity (m^3) __________		Vehicle No. __________ Capacity (m^3) __________		Vehicle No. __________ Capacity (m^3) __________	
DATE	Method of Collection Compacted __________ Uncompacted __________ Vacuumed __________		Method of Collection Compacted __________ Uncompacted __________ Vacuumed __________		Method of Collection Compacted __________ Uncompacted __________ Vacuumed __________	
	Loads	m^3	Loads	m^3	Loads	m^3
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
TOTAL						

PREPARER'S CERTIFICATION

I hereby certify that the information reported on this form represents yard waste generated in the MWC service area and that the materials were separated during the calendar year covered by this application and that the materials were made available for recycling (i.e., composting, mulching) and not combusted.

____
Type Name of Individual, Recycling Coordinator, or Organization/ Business Representative

____
Signature of Individual, Recycling Coordinator, or Organization/ Business Representative

____
Title

____
Date

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-450/3-90-021	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Municipal Waste Combustion: Background Information for Materials Separation		5. REPORT DATE
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Office of Air Quality Planning and Standards U.S. Environmental Protection Agency Research Triangle Park, NC 27711		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO. 68-02-4378
12. SPONSORING AGENCY NAME AND ADDRESS DAA for Air Quality Planning and Standards Office of Air and Radiation U.S. Environmental Protection Agency Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Final
		14. SPONSORING AGENCY CODE 200/04
15. SUPPLEMENTARY NOTES		

16. ABSTRACT

Several issues related to materials separation from municipal solid waste (MSW) are discussed. Current nationwide rates of materials separation and recycling, as well as the methodology for determining municipal solid waste separation rates, are presented. Case studies of four community curbside separation programs include performance data and program costs. Two centralized materials separation facilities which separate materials from unsorted MSW are described with respect to the separation mechanisms employed, performance, and available cost data.

Available data on the impacts of materials separation on municipal waste combustor (MWC) air emissions, combustor operation, and MWC ash are presented. The potential occupational risks of the handpicking process used to separate materials from MSW at some centralized separation facilities are discussed. The use of mercury in household batteries, and current information on community battery separation and collection programs and recycling efforts, are also discussed.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution Municipal Waste Combustors Incineration Pollution Control Materials Separation Costs	Air Pollution Control	13B

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